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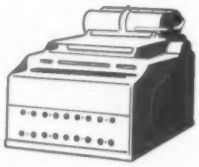

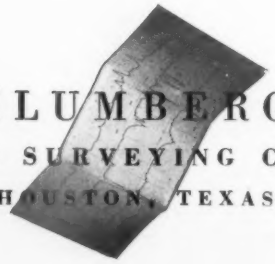

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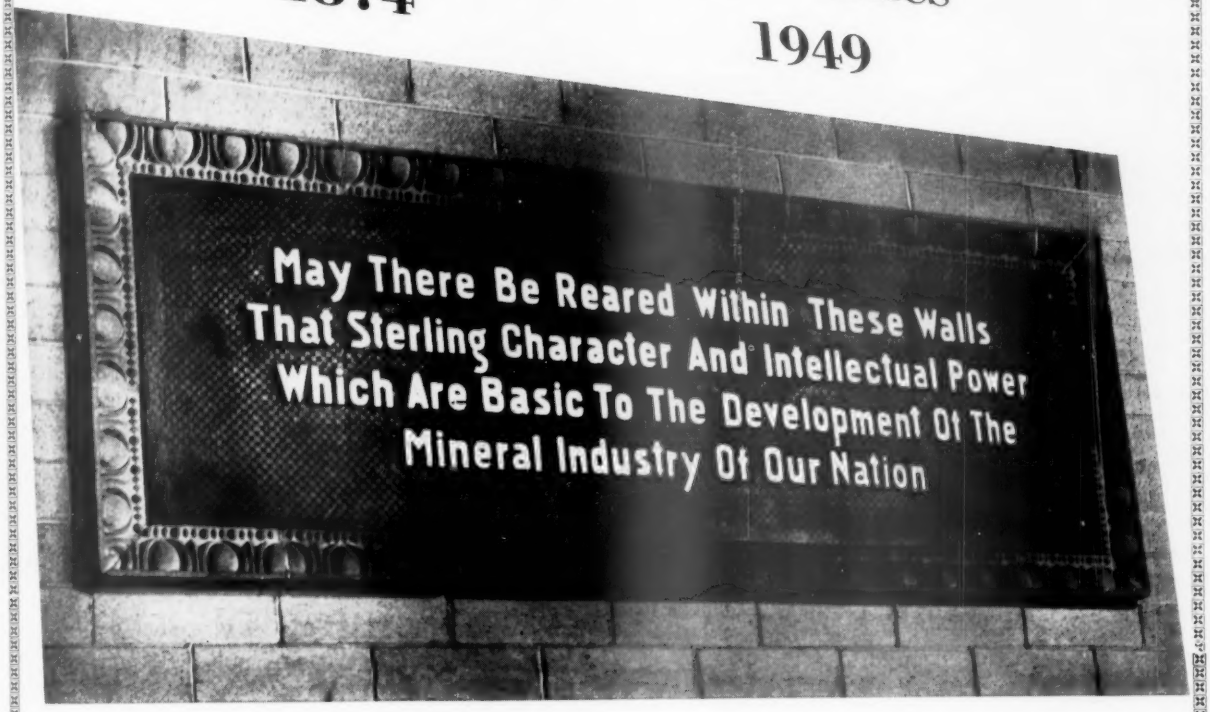
May There Be Reared Within These Walls
That Sterling Character And Intellectual Power
Which Are Basic To The Development Of The
Mineral Industry Of Our Nation

CONGRATULATIONS, MINES

Seventy-five years of pioneering leadership in mineral engineering education will be climaxed with a celebration in Golden on September 29 and 30, and October 1. It is interesting to note that Mines came into being only three years after the AIME, and that the petroleum engineering course at Mines was begun in 1923, only six months after the formation of a Petroleum Division in the AIME. Thus these two traditional institutions have acquired stature and influence together, and their histories have a common thread.

We in AIME share with Mines, and the schools of its kind, the responsibility for meeting the constant challenge to add to our fund of knowledge; to acquire the intellectual power necessary for effective use of our knowledge, and to hold forth for the growth of individual and professional character necessary for *wise* and effective use of our knowledge.

The next 75 years in the mineral industry will demand more than has the past. We heartily wish the Colorado School of Mines success and Godspeed in fulfilling the pledge displayed on the plaque in historic Guggenheim Hall.

THE EXECUTIVE COMMITTEE,
FOR THE PETROLEUM BRANCH

PERSONALS

Officers and guests of the Naval Reserve Petroleum Unit in Washington, photographed on a visit to an Esso Standard Oil Co. refinery in the vicinity. The unit is composed of specialists in all branches of the petroleum industry, and meets weekly for training purposes. Interested persons in the Washington area are invited to participate.

FIRST ROW, left to right: Carl W. Kelly, James H. Collins, Sidney Ritt, E. J. Ceconi, W. R. Bailey, and W. H. Long.

SECOND ROW, left to right: T. C. Snedeker, Lawrence Thompson, Milton H. Bocker, Forrest Tranthum, Clarence W. Hoffer, J. R. Ryan, Paul L. Hopper, and W. E. Reggins.

THIRD ROW, left to right: J. C. Moore, D. L. Newell, Wilfred H. Troup, E. W. Wingerd, William Y. Webb, Richard S. Mason, Clarence E. Ruck, and L. B. Parks.

E. V. WATTS has been appointed production superintendent of the southern division of General Petroleum Corp.'s production department. Watts joined General Petroleum in 1936 as a roustabout in the Lost Hills field. Within a year he had advanced to engineer and in 1948 he was made assistant to the division superintendent. He is a member of the Conservation Committee of California Oil Producers, and the AIME.

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GORDON H. WHITE recently resigned from the Shell Oil Co. to join the ranks of the independent operators. White, after graduation from the Univ. of California, joined the Shell Oil Co. in 1926. At the time of his resignation he was exploration manager of Shell's Midland area. White has now incorporated his own company under the name of Niles Oil Co. and has established headquarters at 1406 M & W Tower Building, Dallas, Texas.

FLORENT H. BAILLY was recently elected to the presidency of Pantepec Oil Co., and Pancoastal Oil Co., both in Venezuela. He has been affiliated with Pantepec since 1928, and has been with the engineering and geologic departments since 1938. He is also president of the Petroleum Engineering Associates, Inc., and Oil Properties Consultants, Inc., of Pasadena, California.

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R. G. HAMILTON, Mid-Continent area manager for Schlumberger Well Surveying Corp., has resigned to return to geological fields. He will continue to reside in Tulsa, with office at 3622 S. Yorktown Place.

Hamilton, with Schlumberger since 1935, was recently promoted to sales manager in Houston but declined in order to remain in the Mid-Continent area.

An authority on electrical logging. Hamilton is a graduate of DePauw with an A.B. in geology, also a graduate of the State University of Iowa with a M.S. and Ph.D. He is a member and past chairman of the Mid-Continent Section, AIME, a past officer of Oklahoma City Geological Society and a

HERMAN E. SCHALLER has been named division sales manager of the Rocky Mountain - Mid-Continent Division of the Eastman Oil Well Survey Co., with headquarters in Denver. A graduate of the Univ. of Southern California, he holds a master's degree in petroleum engineering.

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ALFRED J. LONG, mud engineer for Oil Base, Inc., has returned to the head office at Compton, California, for an extensive training course in White Magic, a new oil-emulsion mud for top-hole drilling now under test. Long is the Texas representative, headquartered at Houston.

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MAX C. EASTMAN was recently appointed as Navy's member of the two-man operating committee for the Elk Hills oilfield, officially termed Naval Petroleum Reserve No. 1. Secretary of the Navy, Francis P. Matthews, appointed Eastman to replace Captain V. H. Wilhelm, USNR, prominent petroleum engineer, who passed away recently in the Naval Hospital in Long Beach.

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HERBERT HOOVER

In elsewhere acknowledging the 75th Anniversary of a school of renown in the mineral industries, we are reminded that August 10 is the 75th birthday of these industries' most distinguished member — 41st President of the Institute, 31st President of the United States.

(Continued on Page 26)

PROGRAM

Petroleum Branch Meeting in San Antonio

October 5, 6, 7

Those planning to attend the San Antonio Meeting should make hotel reservations now, as unusually heavy advance requests indicate a capacity crowd. Address the hotel of your choice among the following: Plaza, Gunter, St. Anthony, White Plaza, and Blue Bonnet. Requests on the Plaza (the headquarters hotel), will be filled with reservations at one of the other hotels. The Westerner, Breckenridge Courts and Ranch Auto Courts are modern and well appointed and are well recommended. The Hotel Committee, under R. K. Guthrie, Seeligson Engineering Company, Transit Tower Bldg., San Antonio, will assist you if your requests upon the hotels or auto courts are not met.

The San Antonio Meeting, tentatively outlined below, promises to be even more enjoyable than past meetings. Additional events and papers may appear on the final program, to be printed in September. The Southwest Texas Section, Raoul Bethancourt, chairman, will be host to the Branch. The social functions have been planned to appeal to the ladies, whose presence is especially desired.

The technical program, with nearly twice the usual number of papers, has been arranged by the Production Technology Committee through Vice Chairman Paul Turnbull, Morris Muskat and Lincoln Elkins. The "General Session" is a joint endeavor of this Committee and the Economics Committee, under R. J. Bradley and Paul Schultz.

Tuesday — October 4

7:00 p.m. to 9:30 p.m. — Advance registration and sale of tickets, Mezzanine.

Wednesday — October 5

8:00 a.m. to 4:30 p.m. — Registration and sale of tickets, Mezzanine.

DRILLING AND CEMENTING OPERATIONS

9:30 a.m. to 11:00 a.m. — Technical Session, Mezzanine Ball Room.

Ability of Drilling Muds to Lift Bit Cuttings, by H. N. Hall, Tulsa; Howard Thompson, Houston; and Frank Nuss, Ft. Worth; Stanolind Oil & Gas Co.

Improved Casing Cementing Practices in the United States, by W. D. Owsley, Halliburton Oil Well Cementing Co., Duncan, Oklahoma.

Squeeze Cementing Operations, by George Howard and C. R. Fast, Stanolind Oil & Gas Co., Tulsa.

NATURAL GAS TECHNOLOGY

9:30 a.m. to 11:00 a.m. — Technical Session, Roof Garden Ball Room.

Performance Characteristics of a Volumetric Condensate Reservoir, by F. A. Allen and R. P. Roe, Stanolind Oil and Gas Co., Tulsa.

Cycling Operations in the La Gloria Field, by William Justice, La Gloria Corp., Corpus Christi, Texas.

Determination of Friction Factors for Measuring Productivity of Gas Wells, by R. V. Smith, U. S. Bureau of Mines, Bartlesville, Oklahoma.

12:00 Noon — General Luncheon, Mezzanine Ball Room (Speaker to be announced later).

WATER FLOODING — GAS CYCLING

2:15 p.m. to 4:30 p.m. — Technical Session, Mezzanine Ball Room.

Applications of the Telefloodmeter to Water Flooding, by Quentin B. Marsh, Sperry-Sun Well Surveying Co., Crossville, Illinois.

Primary Pressure Maintenance with Water Injection in the New Hope Field, Franklin County, Texas, by A. S. Trube, Jr., Tide Water Associated Oil Co., Houston, and Sam N. DeWitt, Seaboard Oil Co., Dallas.

Current Problems in Cycling Operations, by Ralph Hock and Alton J. Carroll, Cotton Valley Operators' Committee, Cotton Valley, La.

2:30 p.m. to 4:30 p.m. — *OPEN MEETING PETROLEUM BRANCH EXECUTIVE COMMITTEE*, Roof Garden Ball Room.

3:00 p.m. — Tea for ladies at home of Mrs. Wm. H. Spice, Jr.

5:00 p.m. to 7:30 p.m. — Cocktail party and open House Petty Geophysical Co.

Thursday — October 6

WELL LOGGING

8:00 a.m. to 12:00 Noon — Technical Session, Mezzanine Ball Room.

Relation Between Electrical Resistivity and Brine Saturation in Rocks, by H. F. Dunlap, H. L. Bilhartz, Ellis Shuler and C. R. Bailey, The Atlantic Refining Co., Dallas.

Selective S. P. Logging, by Henri G. Doll, Schlumberger Well Surveying Corp., Ridgefield, Conn.

The Presence of Conductive Solids in Reservoir Rocks as a Factor in Electric Log Interpretation, by H. W. Patnode and M. R. J. Wyllie, Gulf Research & Development Co., Pittsburgh.

Estimate of Interstitial Water from Electric Logs, by Milton Williams, Humble Oil and Refining Co., Houston.

PHOTOGRAMMETRY — OFFSHORE OPERATION — PUMPING

9:00 a.m. to 12:00 Noon — Technical Session, Roof Garden Ball Room.

Aerial Photogrammetry as Applied to the Petroleum Industry, by Louis Woodward, of Jack Amman Photogrammetric Engineers, San Antonio.

Wave Forces Computed for an Offshore Drilling Site, by Paul L. Horrer, Scripps Institution of Oceanography, La Jolla, California.

Installation of Offshore Pipelines, by H. E. Denzler, James West and J. W. Scott, The California Co., New Orleans.

Dynamometer Charts and Well Weighing, by Leo Fagg, Johnson-Fagg Engineering Co., Tulsa.

12:00 Noon — Ladies' luncheon and style show, gentlemen invited, Colonial Ballroom, Menger Hotel.

2:00 p.m. — GENERAL SESSION, Roof Garden Ball Room.

Opening address (Title to be announced) by William Murray, Chairman, Texas Railroad Commission.

Address (Title to be announced) by L. E. Young, President, AIME, Pittsburgh, Pa.

Address on Synthetic Fuels by A. L. Solliday, Executive Vice-President, Stanolind Oil & Gas Co., Tulsa, Okla.

Legal Aspects of the Tidelands Issue, by Carl Illig, Humble Oil & Refining Co., Houston.

6:00 p.m. to 1:00 a.m. — Petroleum Branch Cocktail Party and Dinner Dance, Club Seven Oaks. Two bands and floor show.

Friday—October 7

RESERVOIR ENGINEERING

9:00 a.m. to 12:00 Noon — Technical Session, Mezzanine Ball Room.

Interpretation of Build Up Curves (Subject to company clearance).

The San Miguelito Field, by WAYNE GLENN, Continental Oil Co., Los Angeles.

Critical Analysis of the Effect of Well Density on Recovery Efficiency, by W. O. KELLER and F. H. CALLAWAY, Stanolind Oil & Gas Co., Tulsa.

Lost Reserves (pro close spacing), by C. W. TOMLINSON, Consulting Geologist, Ardmore, Oklahoma.

PHASE RELATIONSHIPS

9:30 a.m. to 12:00 Noon — Technical Session, Roof Garden Ball Room.

Co-existence of Liquid and Vapor Phases at Pressures Above 10,000 Pounds Per Square Inch, by MICHAEL RZASA, Stanolind Oil & Gas Co., Tulsa, and D. L. KATZ, University of Michigan, Ann Arbor.

Volumetric and Phase Behavior of a Natural Gas Condensate System, by J. C. ALLEN and W. H. BOZE, The Texas Co., Houston.

The Solubility of Carbon Dioxide in Water Both Without and in the Presence of Porous Media, by V. FRED THOMAS, U. S. Army Ordnance Dept., Springfield, Mass., and R. L. HUNTINGTON, School of Chemical Engineering, University of Oklahoma, Norman.

An Electrical Computer for Solving Phase Equilibrium Calculations, by MORRIS MUSKAT and J. M. MCDOWELL, Gulf Research & Dev. Co., Pittsburgh.

Vapor-Liquid Equilibrium Calculations, by PAUL CARPENTER, Phillips Petroleum Co., Bartlesville, Oklahoma.

CORE ANALYSIS

1:30 p.m. to 5:00 p.m. — Technical Session, Mezzanine Ball Room.

Analysis of Fractured Limestone Cores, by F. C. KELTON, Core Laboratories, Inc., Dallas.

Effective Liquid Porosity of Mid-Continent Oil Sands, by R. C. EARLOUGHER and J. M. ROBINSON, Earlougher Engineering Co., Tulsa.

Pore Size Distribution of Petroleum Reservoir Rocks (Subject to company clearance).

Attainment of Connate Water in Long Cores by Dynamic Displacement, by R. L. SLOBOD, The Atlantic Refining Co., Dallas.

Comparison at Capillary Pressure Measurements by Mercury Injection and by Restored State Method, by C. B. SCOTTY and R. W. JOHNSON, The Texas Co., Houston.

FLUID FLOW RESEARCH

1:30 p.m. to 5:00 p.m. — Technical Session, Roof Garden Ball Room.

Liquid-liquid Displacement in a Porous Medium as Affected by Liquid-liquid Viscosity Ratio and Miscibility, by J. P. EVERETT, F. W. GOOCH, JR., and JOHN C. CALHOUN, JR., Dept. of Petroleum Engineering, University of Oklahoma, Norman.

Improvements in the X-Ray Saturation Technique of Studying Fluid Flow, by F. MORGAN, J. M. MCDOWELL and E. C. DOTY, Gulf Research & Dev. Co., Pittsburgh.

Flow of Oil Through Cores, by DONALD L. KATZ, Chem. & Met. Dept., University of Michigan, Ann Arbor.

San Antonio Abstracts and Authors

(Abstracts not appearing here will be carried in the September issue.)

SELECTIVE S.P. LOGGING

H. G. DOLL, Director of Research
Schlumberger Well Surveying Corporation
Member AIME

ABSTRACT

An earlier paper on the general subject of the S.P. log has analyzed the limitations of that log, in particular when dealing with thin permeable beds enclosed in thick highly resistive ones. Under such conditions, the S.P. log does not give a good definition of the permeable beds boundaries.

Selective S.P. logging is a new method which gives accurate determination of the permeable beds, even in highly resistive formations, except when the salinity of the mud is extremely high. It also permits to arrive to a close approximation of the Static S.P.

The method consists generally in controlling the potential of auxiliary electrodes located in the drill hole, in the vicinity of the measuring electrode. In this manner the flow of S.P. current alongside the drill hole is modified, to counterbalance the effect of highly resistive strata.

Several procedures and arrangements to record Selective S.P. curves and Static S.P. curves are explained.

Field examples illustrating these methods are given and discussed.

H. G. DOLL

H. G. Doll received Bachelor of Science degree from the University of Lyon (France) in 1919. He got his engineering degree from the Ecole Polytechnique of Paris in 1923, and then studied two years at the Ecole Nationale Superieure des Mines of Paris. He has been working with Schlumberger since 1926 and at present is Director of Research and Chairman of the Board of Directors of Schlumberger Well Surveying Corp.

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DYNAMOMETER CHARTS AND WELL WEIGHING

L. W. FAGG, Johnson-Fagg Engineering Co., Tulsa

ABSTRACT

The dynamometer card is analyzed on the basis of the significance of instantaneous load changes at various points in the pumping stroke. Also analyzed is the general shape

of the card with relationship to horsepower, undertravel, overtravel, fluid pound, gas lock, excessive friction, and other conditions which cause abnormal operation.

The paper explains how the dynamometer is used to measure the counter-balance effect and graphically solve for the approximate peak torque and illustrates the method for checking standing valve and traveling valve for leaks and wear.

Some new practical uses for the dynamometer will be given. Proven methods are outlined for using dynamometer card information in obtaining more efficient pumping operation. Procedure for well weighing is discussed.

LEO W. FAGG

Leo W. Fagg was graduated in 1935 from Oklahoma A. & M. College with a B.S. degree in industrial engineering. He was employed by the S. M. Jones Co. in 1937 and spent several years analyzing pumping problems and making dynamometer well studies. In March, 1946, he helped to organize the Johnson-Fagg Engineering, specializing in the mechanical problems pertaining to pumping wells.

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IMPROVED CASING CEMENTING PRACTICES IN THE UNITED STATES

WM. D. OWSLEY, Technical Advisor, Halliburton Oil Well Cementing Co., Member AIME

See Los Angeles abstracts.

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LIQUID-LIQUID DISPLACEMENT IN A POROUS MEDIUM AS AFFECTED BY THE LIQUID-LIQUID VISCOSITY RATIO AND LIQUID-LIQUID MISCIBILITY

J. P. EVERETT, Jr. Member of AIME, F. W. GOOCH, JR., U. S. Navy, Guam, and JOHN C. CALHOUN, Univ. of Oklahoma, Norman, Member of AIME

ABSTRACT

This paper presents the results of experiments made by graduate students at the University of Oklahoma on the displacement mechanism. Two separate long core systems made by packing and consolidating sand grains were used. Experiments are reported on the displacement of various oils by water and the displacement of various solutions of sugar in water by other solutions of sugar in water.

Displacement of sugar solution by water or another sugar solution was performed on the system both horizontally and vertically. The ratio of viscosities between the displaced and displacing phases varied from approximately 0.5 to 10.

Displacement of oils by water was performed on horizontal systems only. The ratio of viscosities between the displaced and displacing phases varied from approximately 1 to 100.

All experiments were performed in the absence of a fluid immiscible phase, such as connate water.

Comparisons are made between the displacement of oil by water and the displacement of one sugar solution by another. Both displacements show a primary and secondary phase of displacement as defined by Buckley and Leverett.*

Comparison is also made between the observed experimental results and the theory of displacement as presented by Buckley and Leverett based upon relative permeability concepts.

* Mechanism of Fluid Displacement on Sands, S. F. Buckley and M. C. Leverett (T.P. 1337, February, 1941), AIME Transactions 1942.

JOHN C. CALHOUN, JR.

John C. Calhoun, Jr., received a B.S. and M.S. in petroleum engineering from the Pennsylvania State College. In 1946 he received his Ph.D. degree with a major in petroleum engineering and a minor in chemistry. After spending eight years with Pennsylvania State College as research assistant and instructor in petroleum engineering, he is now professor of petroleum engineering and chairman of the School of Petroleum Engineering, Univ. of Oklahoma, Norman.

F. W. GOOCH, JR.

F. W. Gooch, Jr., was born in Missouri and received a B.S. degree from Univ. of Oklahoma. After serving with the U. S. Navy for several years, he returned to Univ. of Oklahoma and received an M.S. degree in 1949. At present Gooch holds the rank of Lt. Comdr. in the U. S. Navy and is assigned to Guam. He is a member of Sigma Tau and Sigma Gamma Epsilon, professional societies.

J. P. EVERETT

J. P. Everett, a native of Kansas, was graduated from the Univ. of Oklahoma with a B.S. degree in June, 1948, and an M.S. degree in August, 1949. During the war he served four years with the U. S. Coast Guard. He is a member of Pi Epsilon Tau, petroleum engineering honorary society, and he is a junior member of the AIME.

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ADDRESS ON SYNTHETIC FUELS

A. L. SOLLIDAY, Stanolind Oil and Gas Co., Tulsa

ABSTRACT

Interest in the establishment of a synthetic fuels industry has, unfortunately, been greatly influenced by short-term fluctuations in the supply and demand of petroleum products. In determining the desirability or necessity of the immediate establishment of a synthetic fuels industry, two additional factors of prime importance should be considered. Both have been essentially ignored. These factors are (1) current cost and technical status of synthetic fuel processes, and (2) the long-term forecast of supply and demand of petroleum products. The evaluation of these two factors is presented. However, the long-term nature of the problem precludes the use of precise factual information. Therefore, the result of this evaluation is intended to underline the importance of these two factors rather than to supply definitive answers to the twin questions: When will the nation need a synthetic fuels industry, and how large a capacity should such an industry have? Tentative questions, however, are drawn concerning the present and future need for synthetic fuels. In arriving at these conclusions important aspects, such as national security, obsolescence and utility, and economics have each been considered in turn.

A. L. SOLLIDAY

A native of Watertown, Wisconsin, A. L. Solliday received a degree in geology from the Univ. of Oklahoma in 1923. Following his graduation, he was employed as a scout by the Dixie Oil Co. When Stanolind was organized in 1931, he became superintendent of the land department, and in 1944 he was elected a director of the company and vice president in charge of operations. He became executive vice president on January 1, 1948.

AERIAL PHOTOGRAMMETRY AS APPLIED TO THE PETROLEUM INDUSTRY

Louis A. Woodward, Operations Manager, Jack Ammann Photogrammetric Engineers

ABSTRACT

Briefly stated, those associated with the petroleum industry have the problem of locating, producing, refining, and selling the various petroleum products. With the possible exception of selling, aerial photogrammetry has proven to be a valuable tool in many phases of the petroleum industry.

Starting with the geologist, certain types of aerial photographs, indexes and mosaics of most areas serve as a valuable guide to local areas requiring immediate field investigation and also indicate areas of little or no geologic importance. With a minimum amount of field work the photogrammetrist can furnish elevations of any points along beds within the area as may be required by the geologist.

Precise topographic maps compiled by photogrammetric methods have been of great value in locating access roads into well locations and in oil field development and operation. Aerial photographic mosaics and strip topographic maps have been effectively used in pipe line location and construction.

The paper, illustrated by lantern slides, gives brief information on how the various photogrammetric materials are produced and goes into detail about how such materials have been used by the petroleum industry.

LOUIS A. WOODWARD

Louis A. Woodward, operations manager of Jack Amman Photogrammetric Engineers of San Antonio, in the past twenty years has acquired considerable background on the use of photogrammetric methods and materials in various fields of endeavor. He has been active in the American Society of Photogrammetry, being a charter member and president in 1944. He is a member of the American Congress of Surveying and Mapping and the Canadian Institute of Surveying.

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WAVE FORCES COMPUTED FOR AN OFFSHORE DRILLING SITE

Paul L. Horrer, Scripps Institution of Oceanography of the University of California

ABSTRACT

Wave forces play an important part in the design and construction of drilling rigs in shallow water. Information about wave characteristics based upon meteorological data is now being effectively used in preparing plans for some drilling installations. The procedure for obtaining this information at a given location involves three steps: the first utilizes past weather maps, which are readily available, for the computation of wave characteristics in deep water; the second determines the modification of these characteristics as the waves travel into shallow water towards shore; the third, using the shallow water wave characteristics, provides the expected frequencies of forces and moments on engineering structures at the proposed location.

It is the purpose of this paper to illustrate the entire procedure by means of an example. Although the techniques used herein have been described elsewhere, an application of all these techniques to one location has not previously been made generally available.

PAUL L. HORRER

Paul L. Horrer was born in Illinois in 1924. He received a B.S. degree in Meteorology from the California Institute of Technology in 1945. In 1948 he received an M.S. degree in oceanography from the Scripps Institution of Oceanography of the Univ. of California. Now a candidate for a Ph.D., Horrer is employed as an Associate Oceanographer at the Scripps Institute, where he has made several studies of oceanographic conditions at offshore drilling sites.

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APPLICATION OF THE TELEFLOODMETER TO WATER FLOODING

Quentin B. Marsh, Sperry-Sun Well Surveying Co., Crossville, Illinois

ABSTRACT

This sub-surface flowmeter is being used successfully in the Mid-Continent area to determine and control flow rates in water injection wells, in which the casing opposite an upper water bearing sand has been perforated and permitted to gravity or "dump flood" the lower oil zone. It is permanently installed in the well with a packer on sucker rods or tubing and continuously transmits flow rate data to the surface. A battery operated surface recorder records this flow data for daily and cumulative injection rates. The metering element is actuated by the passing fluid, and periodically releases a hammer blow against an anvil. The acoustic impulse is transmitted up the suspension string to the surface. Ball bearings are used throughout. A special oil water seal prevents well water from gaining access to them and reduces friction. Low flow velocities can be metered. Installations are operating on sucker rods to depths of 3,000 feet and on tubing to depths of 2,000 feet. The over-all average period of operation without removal or maintenance currently stands at 327 days. No operating personnel is required. It utilizes warm underground salt water, and offers a completely closed system. It requires sufficient hydro-static fluid head to overcome formation resistance of the zone to be flooded. It brings dump flooding under the category of controlled and engineered water flood at a small portion of the cost a surface injection system would require.

QUENTIN B. MARSH

Quentin B. Marsh is installation engineer for Sperry-Sun Well Surveying Co., Crossville, Illinois. Marsh, a native of Oklahoma, went to work for Sun Oil Company at Evansville, Indiana, as a roustabout in 1940. He served 22 months in the Navy during World War II. In 1948 he joined Sperry-Sun as a sales and service engineer, and is in charge of installation and servicing of the Telefloodmeter.

SQUEEZE CEMENTING OPERATIONS

GEORGE C. HOWARD, Member of AIME, and C. R. FAST, Stanolind Oil and Gas Co., Tulsa

ABSTRACT

Laboratory and field testing of various squeeze cementing materials and techniques revealed that many improvements could be made in squeeze cementing operations. By the use of a slow-pumping squeeze cementing procedure it was possible to control the quantity of cement displaced into a formation and aid in obtaining a high final squeeze pressure. Field testing indicated the desirability of obtaining high final squeeze pressures, the need for improved formation breakdown fluids, and the necessity of controlling the pressure differential during testing after a squeeze job.

C. R. FAST

C. R. Fast joined Stanolind Oil and Gas Co. in 1943, after graduating from the Univ. of Tulsa with a B.S. degree in petroleum engineering. He has been employed as an engineer in the production research laboratory in Tulsa since 1943, and is currently engaged in research on various well completion problems.

GEORGE C. HOWARD

George C. Howard joined Stanolind Oil and Gas Co. in 1940 after graduating from Oklahoma Univ. with a B.S. degree in petroleum engineering, and was employed as a junior petroleum engineer in Oklahoma and Kansas. In 1941 he was transferred to the Stanolind Research Laboratory in Tulsa. Since that time he has been engaged in research on cementing and well completion problems.

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THE SOLUBILITY OF CARBON DIOXIDE IN WATER BOTH WITHOUT AND IN THE PRESENCE OF POROUS MEDIA

V. FRED THOMAS, U. S. Army, Springfield, Massachusetts, and R. L. HUNTINGTON, Univ. of Oklahoma, Norman, Member of AIME

ABSTRACT

A study of the effect of sand on the solubility of carbon dioxide in water was made in a range of pressures from atmospheric to 114.7 pounds per square inch absolute, and temperatures from 32°F. to 80°F. Tests were run on carbon dioxide in the presence of dry sand, sand completely saturated with water, sand 10% saturated with water, and a body of quiescent water. The results indicate that dry sand lowers the vapor pressure of both the water and the carbon dioxide sorbed on the surface and also affects the rate of sorption and desorption of carbon dioxide, as well as the amount of carbon dioxide sorbed.

Pressure and temperature curves are presented for the heating and cooling of various batches of sand and water saturated with carbon dioxide between 32°F. and 80°F. during which pronounced hysteresis effects were observed.

The compressibility factors for carbon dioxide were experimentally determined from atmospheric to 314.7 pounds per square inch at 32°F.

R. L. HUNTINGTON

R. L. Huntington took graduate work in chemical engineering at the Massachusetts Institute of Technology and the Univ. of Michigan, Ann Arbor. His wide experience includes 13 years in the petroleum industry and 16 years as a professor of chemical engineering at the Univ. of Oklahoma, Norman. Huntington has been an active member of the AIME since 1936.

V. FRED THOMAS

V. Fred Thomas was graduated from West Point Military Academy in 1946. During World War II he served with the Ordnance Department of the U. S. Army. Following the war Thomas spent two years taking graduate work in chemical engineering at the Univ. of Oklahoma, Norman. He is now a Lieutenant in the Army Ordnance, stational at present in Springfield, Massachusetts.

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THE PRESENCE OF CONDUCTIVE SOLIDS IN RESERVOIR ROCKS AS A FACTOR IN ELECTRIC LOG INTERPRETATION

H. W. PATNODE and M. R. J. WYLLIE, Gulf Research and Development Company, Pittsburgh, Pa.

ABSTRACT

An investigation of cores from various reservoirs has shown that the apparent formation resistivity factor measured is dependent upon the resistivity of the saline solutions used experimentally for saturating the cores. This effect results from the presence of conducting solid material in the cores, and is shown that the over-all conductivity of any core may be expressed as the sum of the apparent conductivity of the conductive solids in the core and a conductivity which is the quotient of the conductivity of the saturating solution and a true formation factor. Data from experiments on clay slurries are given to support this view. Methods of determining true formation factor both in the laboratory and from electric log data are outlined, and the possibility that dirty formations give rise to anomalous resistivity logs and seriously inaccurate quantitative interpretations is emphasized.

M. R. J. WYLLIE

M. R. J. Wyllie was born in Cape Town, South Africa in 1919. In 1939 he received a B.Sc. degree in applied and industrial chemistry from the Univ. of Cape Town and was elected a South African Rhodes Scholar to Oxford where he took a Ph.D. degree in 1943. After several years in the British Royal Navy, he became a courtesy fellow of the Johns Hopkins Univ. in 1946. A year later he joined Gulf Research and Development Co., Pittsburgh.

H. W. PATNODE

H. W. Patnode was born in Pittsfield, Massachusetts, in 1909. In 1933 he received an A.B. degree from Cornell and two years later received an M.A. degree in geology, also from Cornell. For several years he worked as a fellow for the A.P.I., joining the Gulf Research and Development Co., Pittsburgh, in 1941. He is a member of A.A.A.S., A.A.P.G., A.C.S., and A.G.U. Patnode has published several prior papers on petroleum research.

ABILITY OF DRILLING MUDS TO LIFT BIT CUTTINGS

W. F. Nuss, Member AIME, H. N. Hall, and H. M. Thompson, Stanolind Oil and Gas Co., Tulsa

ABSTRACT

Removal of bit cuttings is an important function of drilling muds. In an effort to obtain better understanding of the factors influencing the removal of cuttings, an extensive series of laboratory tests was made in which slip velocities of various sizes and shapes of particles were measured in muds of different physical properties. Empirical equations were then derived from these experimental data. These equations show that slip velocity is dependent on cutting size and shape, mud flow constants, and flow regime of the mud. Applicability of these equations for field use is demonstrated by comparing computed slip velocities with slip velocities obtained from field tests.

H. N. HALL

H. N. Hall is a Junior Research Engineer with the Stanolind Oil and Gas Co.'s Research Department, Tulsa. A native of Tulsa, Oklahoma, Hall was graduated from Oklahoma A. & M. College with a B.S. degree in chemical engineering. After graduation he served three years with the U. S. Air Force. He then came to Stanolind and for the past two years has been engaged in research on drilling muds.

HOWARD M. THOMPSON

Howard M. Thompson, drilling research engineer for the Stanolind Oil and Gas Co., received a B.S. in chemical engineering in 1934. After working in various capacities in drilling operations for the next seven years, he started with Stanolind in 1941 and worked as a mud engineer on the Gulf Coast until 1943. In 1947 he returned to the producing department to carry out a drilling research program in West Texas. He is currently in the Gulf Coast Division, Houston.

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THE RELATION BETWEEN ELECTRICAL RESTIVITY AND BRINE SATURATION IN RESERVOIR ROCKS

H. F. Dunlap, H. L. Bilhartz, C. R. Bailey, Members AIME, and Ellis Shuler, The Atlantic Refining Co., Research Laboratories, Dallas

ABSTRACT

Data are presented which indicate that the saturation exponent, n, in the equation $R_s = R_{100}^{-n}$, relating core resistivity, R_s, to the resistivity at 100 per cent saturation, R_{100}, and to the saturation, S, may vary appreciably from the value of two which is usually assumed for this exponent when interpreting well logs. Values ranging from one to two and one-half have been found on core samples investigated to date. Attempts to correlate this saturation exponent with porosity or permeability of the core have not been successful. The saturation exponent is apparently not a function of the interfacial tension between the brine and the displacing fluid. Some evidence is given indicating that the resistance of the core is not a unique function of the saturation but depends upon the manner in which this saturation was achieved. Equipment and technique are discussed for measurement of resistivities in core plugs in which water saturation can be varied.

H. F. DUNLAP

H. F. Dunlap was born in Ennis, Texas in 1916. He attended Rice Institute where he was graduated in 1938. In 1939 he received an M.A. degree in physics and in 1941 a Ph.D. in physics. After doing research work in physics at the Univ. of New Mexico, he joined the Atlantic Ref. Co., Dallas, in 1945 where he is currently employed as a senior physicist in production and geophysical research.

HARRELL L. BILHARTZ

Harrell L. Bilhartz is a native of Texas, having lived near the oil fields of Breckenridge from 1922 to 1939. He was graduated from Southwestern Univ. with a B.S. degree and attended the graduate schools of Harvard Univ. and Massachusetts Institute of Technology. Three years in the U. S. Navy followed, after which he became associated with The Atlantic Ref. Company as a chemical engineer in charge of field problems and material evaluation.

ELLIS SHULER

Shuler, a native of Texas, graduated from Southern Methodist Univ. and from California Institute of Technology with an M.S. degree. For several years he was occupied in seismograph work in domestic and foreign service. He later attended the graduate school of Harvard Univ. where he was active in radar research work for the Army. He is currently employed in the Research and Development Department of The Atlantic Ref. Co.

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THE COEXISTENCE OF LIQUID AND VAPOR PHASES AT PRESSURES ABOVE 10,000 POUNDS PER SQUARE INCH

Michael J. Rzasa, Stanolind Oil and Gas Company, Tulsa, and Donald L. Katz, Univ. of Michigan, Ann Arbor, Members of AIME

ABSTRACT

With greater effort being devoted to the discovery of new oil and gas reserves and a consequent increase in bottom hole pressures due to greater drilling depths, the phase relationships of hydrocarbon fluids at pressures above 10,000

pounds per square inch are becoming increasingly important.

The present paper discusses the results of research with a windowed cell on a methane-Kensol 16 system to pressures of 25,000 pounds per square inch and temperatures to 260°F Kensol 16 is a commercial high narrow-boiling-range oil. It is shown that for the temperature range of 60°F to 260°F, this particular system exists in two phases to pressures of approximately 14,000 pounds per square inch. and data are presented giving the relative amounts of liquid and vapor phases coexisting under these conditions. Partial phase diagrams are shown for six different mixtures of methane and Kensol 16, three of which include the critical region.

In contrast to mixtures composed of substances of fairly close volatility, critical opalescence was noted for as much as ±200°F of the critical temperature.

The critical locus of the methane-Kensol 16 system was estimated and the conventional pressure-composition and temperature-composition diagrams were prepared. From these, the equilibrium vaporization factors for methane and Kensol 16 were estimated for temperatures from 60°F to 700°F and to pressures above 12,000 pounds per square inch.

The relations of this study to petroleum production problems and other phase equilibria research are discussed.

MICHAEL J. RZASA

Michael J. Rzasa joined the Research Department of the Stanolind Oil and Gas Company as research engineer in October, 1947, after obtaining the M.S. and Ph.D. degrees in chemical engineering from the Univ. of Michigan. His undergraduate training was obtained at Yale Univ. In August of 1948, Rzasa was promoted to research group supervisor and placed in charge of the Hydrocarbon Phase Equilibria and Thermodynamics Group.

DONALD L. KATZ

Donald L. Katz received the Ph.D. from the Univ. of Michigan in 1933. He joined Phillips Petroleum Co. in 1933 as research engineer and in the next three years did pioneer work in the field of reservoir engineering. Since 1936 he has been professor of chemical engineering and metallurgy at the Univ. of Michigan. He is active in AIME and AICHE and is the author of numerous papers on the behavior of hydrocarbons.

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CRITICAL ANALYSIS OF THE EFFECT OF WELL DENSITY ON RECOVERY EFFICIENCY

W. O. KELLER and F. H. CALLAWAY, Stanolind Oil and Gas Company, Tulsa, Members of AIME

ABSTRACT

The history of the well spacing problem is reviewed briefly, including economic and legal considerations which have influenced actual drilling practices. Engineering thought on the well spacing problem has been traced concurrently and the basis for opinions prevailing at various times is pointed out.

The various theories as to the well spacing-recovery relationship have been reviewed in considerable detail and these theories analyzed in terms of their consistency with modern reservoir engineering concepts. It is concluded that the well spacing problem must be analyzed in terms of recovery efficiency and that a sound answer to the well spacing problem has not and probably will not be available from production history of wells and fields.

An engineering analysis designed to permit calculation of recovery efficiencies as a function of well spacing from basic reservoir data is presented. Results of this type analysis indicate that the effect of well spacing on recovery efficiency in depletion type reservoirs will be very small. Limitations of this approach are pointed out, particularly with respect to its application in lenticular reservoirs.

Testing techniques are outlined which should indicate whether or not a reservoir is continuous between wells and whether or not satisfactory drainage is being obtained with present spacings. A mass of data of this type indicates continuity to exist in most fields.

F. H. CALLAWAY

F. H. Callaway was graduated from the Univ. of Texas in 1946 with a B.S. degree in petroleum engineering. Since then he has been employed in the capacity of reservoir engineer by the Stanolind Oil and Gas Co. in Tulsa. His work in that capacity has been confined primarily to evaluation of secondary recovery projects, to reservoir engineering training, and to the application of research developments to oil field production practice.

W. O. KELLER

W. O. Keller, a native of San Antonio, Texas, graduated from the Agricultural and Mechanical College of Texas in 1941, with a B.S. in petroleum engineering. Upon graduation, he was employed by the Stanolind Oil and Gas Co. as a roustabout engineer in the East Texas field. For the past two years he has been in charge of the reservoir engineering work for the Stanolind Oil and Gas Co., Tulsa.

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LOST RESERVES

C. W. TOMLINSON, Ardmore, Oklahoma, Member AIME

ABSTRACT

Statistical analysis of reservoir data assembled by the A.P.I. well-spacing committee indicates larger recoveries

from close spacing than from wide, in inverse ratio to distance between wells.

Equations of constant radial flow have been used to demonstrate that little more energy is consumed in draining a large area than a small one. In a field produced to capacity, however, except for a brief initial interval, oil flows more rapidly into wide-spaced wells. When this increase of velocity with increased drainage radius is introduced into radial flow equations, a corresponding increase is indicated in energy consumption per barrel of oil produced. Curtailing production does not eliminate this waste of energy.

Many fields have been depleted of reservoir energy while producing only a small fraction of their recoverable oil. Down to a limiting "critical spacing," energy is conserved and primary recovery is increased by closer spacing of wells.

C. W. TOMLINSON

PRESIDENT
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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PRIMARY PRESSURE MAINTENANCE WITH WATER INJECTION IN THE NEW HOPE FIELD, FRANKLIN COUNTY, TEXAS

ALBERT S. TRUBE, JR., Tide Water Associated Oil Co., Houston, and SAM N. DEWITT, Seaboard Oil Co. of Delaware, Dallas, Members of AIME

ABSTRACT

This paper presents a discussion of the pressure maintenance operations which were begun in the New Hope Field in 1944. The project has required the injection of extraneous waters at depths from 7,300 to 8,000 feet with intake well-head pressures up to 4,000 psi.

Records of oil and water production, water injection and gas-oil ratios have been kept for each reservoir and reservoir pressures were taken at regular intervals. These data indicate that the Bacon Lime reservoir had no apparent water encroachment up to the time of water injection. However, the Pittsburg and Hill Sands had some natural water influx but not sufficient to prevent pressures from declining below the bubble point. It also is indicated that the Bacon Lime and Hill Sand reservoirs responded almost immediately to water injection while the Pittsburg Sand which is the least permeable has shown good pressure response only during the past year.

The principle objective of the project has been to increase ultimate recovery. Success of the project to date also has resulted in reduced lifting costs. Estimates based on the initial water break-through patterns indicate that the principle objective of substantial additional recovery will be accomplished with a possibility that the original estimates of oil recovery with pressure maintenance will be exceeded.

SAM N. DeWITT

Sam N. DeWitt, a native of Oklahoma, graduated from Oklahoma A. & M. College in 1931 with a B.S. degree in civil engineering. He was with the Oklahoma State Highway Department from 1931 to 1934; with Geophysical Service, Inc., and the Coronado Corp., until 1942 when he joined Seaboard Oil Co. of Delaware. Since January, 1945, he has been a petroleum engineer in the general office of the Mid-Continent Division, Dallas.

ALBERT S. TRUBE, JR.

Albert S. Trube, Jr., was born in New Mexico in 1914. He received his B.S. degree in petroleum production engineering from The Univ. of Texas in 1936. From then until 1944 he was with the Oil and Gas Division of the Texas Railroad Commission. Since 1944 he has been with Tide Water Associated Oil Co., and for the past four years his work has been concerned mainly with petroleum reservoir engineering.

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ATTAINMENT OF CONNATE WATER IN LONG CORES BY DYNAMIC DISPLACEMENT

ROBERT L. SLOBOD, Member AIME, The Atlantic Ref. Co., Dallas

ABSTRACT

One purpose of this paper is to point out that in much of the work reported in the literature on long cores true connate values probably have not been obtained. This condition is a result of failure to maintain flow of displacing oil for a time interval sufficiently long to attain equilibrium. The establishment of irreducible water (connate water) by flowing oil through a long core originally 100 per cent saturated with brine has been found to be a slow process because of the extremely large number of pore volumes of oil which pass through the system before irreducible water is attained.

A satisfactory method for establishing connate water in long cores has been developed in which the core is mounted in a rubber sleeve, and flow of oil is maintained until no additional water is displaced. In one specific case a continuous flow of oil was maintained for 37 days with the passage of 2452 pore volumes of naphtha through an 18-inch core before an irreducible water saturation of 15 per cent was

produced. In contrast, the more usual method of flooding with only a few pore volumes (3) of oil yielded an interstitial water value of 33 per cent in the same core. The difference between these numbers is striking and is important in evaluating recoverable oil. For example a considerably higher percentage of the in place oil (79 per cent) was recovered in a water flood of the core containing 15 per cent connate water than in a similar flooding of the same core containing 33 per cent initial water (only 55 per cent of the in place oil recovered).

ROBERT L. SLOBOD

R. L. Slobod was born in Pennsylvania in 1914. In 1935 he received a B.S. degree in chemistry from Union College, Schenectady, New York. Four years later he received a Ph.D. in physical chemistry from Northwestern Univ., Evanston, Illinois. He joined the Atlantic Ref. Co., Dallas in 1944, after several years with the Bell Telephone Laboratories, New York. Slobod is a member of the American Chemical Society and the AIME.

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EFFECTIVE LIQUID POROSITY OF MID-CONTINENT OIL SANDS

R. C. EARLOUGHER and J. M. ROBINSON, Members AIME. Earlougher Engineering, Tulsa

ABSTRACT

Effective liquid porosity has been found to be usually less than the normal effective porosity now being determined by the industry in general. It is the purpose of this paper to present the results of numerous determinations of total effective liquid porosity.

During the past six years, the total oil plus water saturation determined after flooding samples with water in the laboratory has been used to obtain what is believed to be a more correct porosity value. Recently this factor has been checked and found to be true. After flooding samples with fresh water at 40 psi pressure gradient for approximately 10 hours, unfilled voids are measured by use of a calibrated mercury pump. This procedure measures the penetration of mercury into the core sample at 1000 psi. The oil and water saturation plus the mercury penetration is believed to represent effective porosity. The use of a large sample of approximately 100 cc or greater is essential for the determination.

The total effective liquid saturation measured in this manner has been found to be equivalent, on the average, to 94 per cent of the normal porosity determined from adjacent ¾-inch diameter samples. A total of 1300 samples, from 130 wells in 15 different pools have been analyzed. Total effective liquid porosity has been found to vary from 80 to 112 per cent of the normal porosity with the values for 70 per cent of all wells lying between 85 to 95 per cent of the normal porosity.

This error in porosity measurement is very significant in estimating oil reserves when using the pore volume method of computation. A six per cent error in porosity may result in an error of from 20 to 40 per cent in calculations of either primary or secondary oil recovery.

J. MILTON ROBINSON

J. Milton Robinson graduated from the Univ. of Tulsa in 1943 with a degree in petroleum engineering. Since 1940 he has been employed by Earlougher Engineering and is currently in charge of the core laboratory. Robinson's work for the past nine years has dealt with the analyses of cores from oil producing areas from the Rocky Mountains eastward, and the interpretation of results of these analyses with regard to secondary recovery.

R. C. EARLOUGHER

R. C. Earlougher graduated from the Colorado School of Mines in 1936 with a degree in petroleum engineering. In 1938 he purchased, with a partner, the Geologic Standards Co., Tulsa. Three years ago he became sole owner and has since operated under the name of Earlougher Engineering. He is a past chairman of the Mid-Continent Section of the AIME and is a nominee for the Petroleum Branch Executive Committee for 1950.

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San Antonio Exhibitors

At Fall Meetings the exhibit booths presented by leading equipment and service organizations provide a wealth of information and enhance the meeting atmosphere.

Among the companies preparing exhibits for the San Antonio Meeting are:

A-1 Bit and Tool Company
Baker Oil Tools, Inc.
Baroid Sales Division, National Lead Co.
Core Laboratories, Inc.
Dowell Incorporated
Geo. E. Failing Supply Co.
Halliburton Oil Well Cementing Co.
Keystone Development Corp.
Lane-Wells Co.
M. O. Johnston Oil Field Service Corp.
Oil Center Tool Co.
Otis Pressure Control, Inc.
Schlumberger Well Surveying Corp.
Shaffer Tool Works
Sperry-Sun Well Surveying Co.
Welex Jet Services, Inc.

PROGRAM

Petroleum Branch Meeting in Los Angeles

October 20-21

The Los Angeles meeting will conform to the pattern used in the previous years. The meeting will be held on October 20-21 at the Elks Club, 607 South Parkview Street. Exhibits by equipment and service companies will be presented as in the past. The version of the program which appears below is a tentative one which will be confirmed and supplemented by announcements in the September JOURNAL.

Thursday—October 20

GENERAL INTEREST

Morning Session

Recent Developments in Offshore Drilling, Gulf Coast, by DEAN A. MCGEE, Kerr-McGee Oil Industries, Inc., Oklahoma City.

Petroleum Developments in Canada, by J. D. GUSTAFSON, Imperial Oil Limited, Calgary, Alberta, Canada.

SIGNIFICANT CALIFORNIA FIELDS

Afternoon Session

Kuyama Valley Oil Field, by CHESTER A. DAVIS and W. A. PAYNE, Richfield Oil Corp., Los Angeles.

The Lake View Oil Field, by W. P. SIMS and W. G. FRAILING, Standard Oil Co. of California, Taft.

The San Miguelito Field, by WAYNE GLENN, Continental Oil Co., Los Angeles.

Friday—October 21

TECHNOLOGY

Morning Session

Some Aspects of Relative Permeability, by S. T. YUSTER, Univ. of California at Los Angeles.

Fluid Saturation in Porous Media by X-Ray Technique, by A. D. K. LAIRD and J. A. PUTNAM, Univ. of California.

EQUIPMENT AND OPERATIONS

Afternoon Session

Improved Casing Cementing Practices in the United States, by WM. D. OWSLEY, Halliburton Oil Well Cementing Co., Duncan, Oklahoma.

The S.P. Log in Shaly Sands, by H. G. DOLL, Director of Research, Schlumberger Well Surveying Corp., Ridgefield, Connecticut.

Corrosion Mitigation Within Dehydrating Tanks, by ERNEST KARTINEN, Signal Oil and Gas Co.

Los Angeles Abstracts and Authors

RECENT DEVELOPMENTS IN OFFSHORE DRILLING, GULF COAST

DEAN A. McGEE, Member AIME, Kerr-McGee Oil Industries, Inc.

ABSTRACT

More than one hundred million dollars has been spent by 35 American oil companies during the last four years in exploring and drilling for oil beneath the submerged waters of the continental shelf off the Louisiana and Texas coasts. Seventeen fields have been discovered — eight oil, seven gas-condensate, and two dry gas — but none has yet developed into major significance. These fields now are producing about 2,500 barrels of oil daily.

There are currently some 35 operations in the offshore area, of which about one-half are inactive locations or platforms.

Most intensive leasing has been off the Louisiana coast, where 757 tracts, totaling 2,548,941 acres, have been leased. About one-fourth of the acreage has been surrendered, leaving a total of 1,926,519 acres currently under lease.

Geophysical work reached its peak in January, 1948, when there were 28 reflection seismograph crews and two gravity meter crews working. Since that time geophysical activity has declined gradually and now there are only five crews at work in the area.

Drilling now follows two general patterns, one employing a large self-contained platform on which all drilling equipment, crew quarters, etc. are located. The other is a combination of small platform with floating drilling tender, which seems to be gaining in favor because of its greater portability and lower construction costs.

Platform construction is of two general types, one using a small number of large diameter steel tubular pile, braced by pre-stressed steel cable. The other employs a larger number of smaller diameter steel piling driven through jackets or templates prefabricated on land and floated to location.

Factors contributing to the slow-up in offshore drilling are: (1) Reduced demand for crude oil, (2) Disappointing results obtained in drilling, and (3) The unsettled tidelands-ownership question.

DEAN A. McGEE

Dean A. McGee was born in Kansas in 1904. He obtained a degree in mining engineering from the Univ. of Kansas in 1926, taught at Kansas Univ. one year, and then joined Phillips Petroleum Co. In 1937 McGee became vice president in charge of production and exploration for Kerlyn Oil Co., was designated executive vice president in 1942, and in 1946 the company name was changed to Kerr-McGee Oil Industries, Inc.

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CORROSION MITIGATION WITHIN DEHYDRATING TANKS

ERNEST KARTINEN, Signal Oil and Gas Co.

ABSTRACT

"Corrosion Mitigation Within Dehydrating Tanks" is a progress report covering eight years of experience in attempting to prevent corrosion and increase the useful life of such installations. The accepted practice of using protective coatings is touched upon, as well as the use of galvanized tanks. With the evident ineffectiveness of all these measures, an experiment in the use of cathodic protection of the installations was started two years ago. The experiments are as yet incomplete but not inconclusive. The results thus far are very favorable and this paper is intended only as a progress report of an experiment.

ERNEST KARTINEN

A native of the state of Washington, Ernest Kartinen attended Washington State College for four years. He was graduated with a Bachelor of Science degree in mechanical engineering in 1935. Kartinen joined the Signal Oil & Gas Company in 1941 as a mechanical engineer and has remained with that company until the present time. He has been outstanding in California petroleum circles and holds an active membership in API and NACE.

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THE S.P. LOG IN SHALY SANDS

H. G. DOLL, Director of Research
Schlumberger Well Surveying Corporation

ABSTRACT

As a continuation of the earlier paper on the general subject of the S.P. log, a more complete analysis of certain features of the S.P. log in shaly sands is given. The pseudo-static S.P. in front of shaly sands is compared, on a theoretical basis, to the static S.P. in front of clean sands, as a function of the respective amount of shale and sand in the formation, and of the relative resistivities of the shale, of the uncontaminated part of the sand, and of the invaded zone of the sand.

As a conclusion, the advantage of using reasonably conductive mud in this case is shown.

The discussion is illustrated by field examples.

See San Antonio for biography and picture.

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FLUID SATURATION IN POROUS MEDIA BY X-RAY TECHNIQUE

A. D. K. LAIRD and J. A. PUTNAM, Member of AIME
University of California

ABSTRACT

This paper describes the application of x-ray theory to design procedures in connection with fluid saturation determinations during fluid flow experiments with porous media. A reliable and rapid method for calibrating the x-ray apparatus is described. Extension of the method to fluid saturation determinations in three-fluid systems is described.

ALAN D. K. LAIRD

Alan D. K. Laird was born in Victoria, Canada, and received his B.S. degree in mechanical engineering from the Univ. of British Columbia in 1940. He then joined the construction engineering staff of Defense Industries Ltd. of Montreal, Canada. His present position is lecturer in the Department of Mechanical Engineering of the Univ. of California, at Berkeley, where he has spent three years in graduate study.

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IMPROVED CASING CEMENTING PRACTICES IN THE UNITED STATES

WM. D. OWSLEY, Technical Advisor, Halliburton Oil Well Cementing Co., Member AIME

ABSTRACT

Much emphasis has been placed in recent years on the securing of successful casing cementing jobs. A number of procedures used in various oil areas of the United States for securing successful casing jobs are discussed. The development of a new type cementing plug, together with theory of two-plug operation and its importance is detailed.

Other items covered include use of mechanical wall cleaners, admixes to cement slurries and special devices for casing cementing as used in a number of areas.

W. D. OWSLEY

W. D. Owsley, a native of Chickasha, Okla., attended Georgia School of Technology and Univ. of Oklahoma, where he received his degree in petroleum engineering in 1931. He joined Halliburton Oil Well Cementing Co. at that time. Since then he has served the company as division engineer for the Gulf Coast, division engineer for California, designing engineer, mechanical research supervisor, and chief engineer. Since 1947 Owsley has been technical advisor for the Halliburton organization.

A Method of Embedding Large Cores in Plastic For Fluid Flow Studies

By the Petroleum and Natural Gas Division of the Pennsylvania State College

Abstract

A technique of preparing porous bodies for fluid-flow studies is described including the embedment of the porous medium in an impermeable, Lucite[1] sheath. The method of plastic encasement requires no elaborate molding mechanisms, the Lucite being formed under moderate pressures and temperature from a mixture of methyl-methacrylate polymer granules in monomer. Cores two inches in diameter and 30 inches in length have been successfully mounted in Lucite using the technique described. Indications are that larger cores could be successfully mounted.

The development work reported herein was conducted by the Petroleum and Natural Gas Division of The Pennsylvania State College. The work was initiated under the sponsorship of the Pennsylvania Grade Crude Oil Association and completed under the sponsorship of South Penn Oil Company.

The following individuals have contributed to the development of the technique: J. C. Calhoun, Martin Felsenthal, J. H. Henderson, John W. La Rue, R. L. McCormick, R. A. Morse, A. T. Sayre, Keith Sheppard, K. W. Smith, P. L. Terwilliger, and S. T. Yuster.

In the study of flow through porous media it is desirable to encase the porous body in some medium which will effectively restrict all flow to the pore matrix. Auxiliary requisites of such a casing are that it be inert to the fluids used, impermeable to gas and liquids, and that it provide a strong, tough, machineable sheath without penetrating the porous body. It is also desirable to have a considerable degree of transparency. This feature permits the visible detection of areas of imperfect bond between the porous material and the plastic sheath. Imperfections of this sort, if undetected, will introduce errors in porosity and fluid saturation determinations, as well as provide channels through which the flowing fluids may by-pass considerable portions of the porous matrix.

To fulfill the above requirements this laboratory has conducted a lengthy program of development work on the embedment of cylindrical sandstone cores in a suitable plastic. The result has been the choice of methyl-methacrylate polymer (Lucite) as the most practical plastic coating, for laboratory application. There are numerous other plastics, particularly in the thermo-setting classification, which have certain advantages over the methyl-methacrylate resin. However, for large cores the methyl-methacrylate polymer has proved the most feasible material for fabrication using laboratory equipment commonly available. Lucite absorbs small quantities of water. For small cores, where accurate gravimetric saturation determinations are necessary, this is a decided disadvantage; for the large systems described in this paper, volumetric measurements predominate and this characteristic provides no serious difficulty.

The first embedment of large cores in Lucite was accomplished by compression molding. Although moderate success was attained, the degree of temperature and pressure control needed to produce stress-free Lucite moldings was difficult to obtain with the limited facilities available. The monomer-polymer dough technique outlined by the E. I. du Pont de Nemours & Company, Inc.[2] appeared to present a solution to the problem provided the core could be sealed sufficiently well to insure no penetration of the core by methyl-methacrylate monomer.

A description of the finished product may help to clarify the procedural steps to be detailed in subsequent paragraphs. The porous bodies ready for flow tests consist of cylindrical cores, 2 in. in diameter, thinly coated with a transparent, sealing-coat of Baker casting resin[3], which in turn is covered with a radial sheath of Lucite up to ½ in. in thickness. The core surface is contacted with gold-plated brass electrodes placed at suitable intervals along the length of the core and diametrically opposed to each other. Between these pairs of electrodes are located piezometric rings formed by a thin ring of pulverized NaCl placed on the core surface prior to coating it with Baker resin. Suitable connections to these electrodes and piezometric rings are made by subsequent machining of the Lucite sheath.

After the core has been mounted in Lucite, the ends are cut off, and machined Lucite end plates are cemented to the core sheath. Fig. 1 shows the entire core complete with the fittings described above and ready for fluid flow tests. Fig. 2 is a close-up of one end of the completed core mount. Note the electrodes, the pressure taps, and the ¼ in. Saran tubing cemented directly to the end plate.

[1] References given at end of paper.

Inasmuch as the monomer-polymer dough[4] technique of plastic molding involves the use of a free liquid phase, the porous body must first be sealed with an impermeable non-penetrating barrier material which will prevent Lucite invasion. This impermeable seal must fulfill three requirements of considerable importance: (a) It must be insoluble in the methyl-methacrylate monomer; but possess a considerable degree of affinity for the methyl-methacrylate polymer. (b) The sealer must have no tendency to inhibit the polymerization of the methyl-methacrylate. (c) It should be preferably transparent, or at least reasonably translucent. The material used in the technique described is a Baker casting resin[5], a phenol-formaldehyde resin easily applied and readily obtained. Although it does not fully fulfill the requirements specified above, it has been the most satisfactory sealer. Its greatest weakness seems to be the fact that there is very little adhesive bond between the two polymerized resins. Indeed the resulting bond between the resins seems to be almost entirely due to the radial shrinkage of the methyl-methacrylate as it polymerizes and cools.

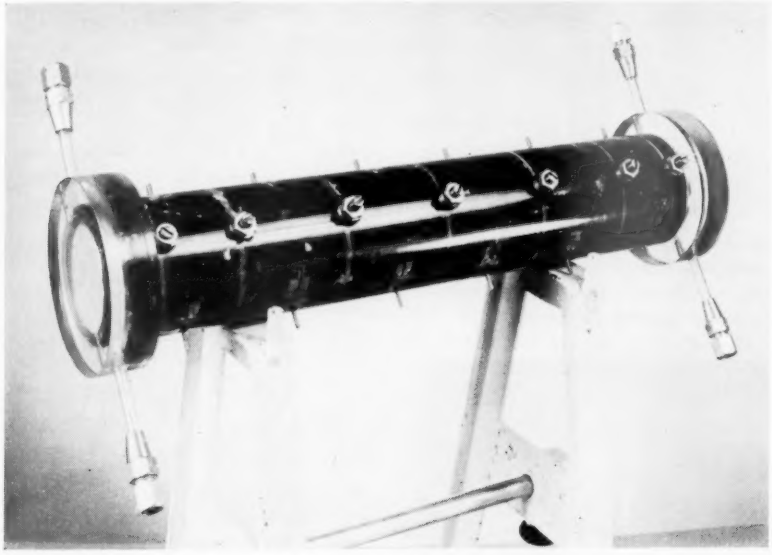


FIG. 1 — LUCITE MOUNTED CORE COMPLETE WITH FLOW CONNECTIONS,

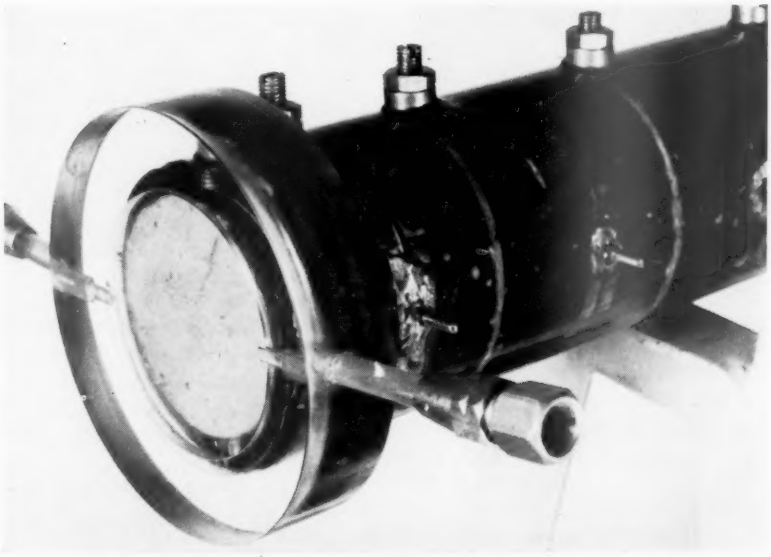


FIG. 2 — CLOSE UP OF LUCITE MOUNTED CORE SHOWING DETAIL OF FITTING ELECTRODES, AND PRESSURE TAPS

The ultimate choice of Baker resin as a sealer was largely dictated by a trial and error method. Numerous sealers were tried with varying degrees of success. The most discomfiting obstacle was, and is, to find a sealer which when polymerized will have some affinity for Lucite and which will resist the solvent action of the methyl-methacrylate monomer. Numerous thermosetting plastics held promise. However, those plastics which pass through a gel state during the initial stage of polymerization are difficult to apply to the core at just the proper instant. Application before gelling occurs, results in excessive penetration. Application after gelation has begun tends to destroy the gel structure and retards the polymerization.

Core Preparation

The preliminary steps in preparing the porous body for mounting in Lucite may be divided into three phases:

(1) Cleaning the core to insure a clean surface for the contacting resin. (2) Fitting the core with electrodes and piezometric rings to facilitate subsequent measurement of pressures and electrical resistance during flow tests.

(3) Coating the core with an impermeable sealer which will prevent the free liquid phase of the monomer-polymer dough from saturating the porous body.

Cleaning cores taken from oil-bearing strata has not been difficult. Considerable oil may remain in the matrix during the mounting procedure if the surface is thoroughly cleaned. After mounting, this oil may be removed by solvent extraction. The procedure used in this laboratory is to scrub thoroughly the surface with naphtha, then soak the core in warm naphtha for several days until the rate of extraction by diffusion is visibly slowed. The core is then dried at moderate temperatures before proceeding with further preparation. When the

core has been cleaned and dried the electrodes and salt rings are attached to the core surface.

The electrodes used consist of rectangular pieces of gold-plated, brass shim stock 0.003 in. thick. Two electrodes are diametrically opposed at suitable intervals along the length of core thus providing a resistance measurement dependent upon a flow of electrical current perpendicular to the direction of fluid flow. The electrodes are wired to the core surface with copper wire, a drop of solder placed on each, and they are then cemented to the core with a thin coating of Baker resin placed around the perimeter of the electrode. This resin is polymerized at 70°C. before the copper wire is cut from between the electrodes which are then held in place only by the resin. It is necessary that the Baker resin be polymerized to a thick, viscous state before being applied to the core. This insures no penetration of the porous material by the resin, and no invasion of the resin under the electrodes.

The piezometric rings are formed by placing a thin ring of NaCl on the clean core surface at desired intervals. This salt ring is later dissolved by flowing fresh water through the core. The NaCl is pulverized in a ball-mill to a very fine powder, moistened enough to make it plastic, then applied by spatula to the core in a ring 1/16 in. wide, just sufficiently thick to insure circumferential continuity of the peizometric ring when the salt is later dissolved. This salt becomes a hard stable ring when dried.

Upon completion of the above operations, the core is now ready for its sealing coat of Baker resin. It has been found desirable to apply this coat to a warm core (50 to 70°C.) in as thin a layer as possible which will still insure an impermeable seal. The resin is allowed to polymerize to an almost stringy consistency before being applied to the core. It is important to stress the need of a uniform layer of this sealing resin. Permitting the resin to be thick in spots not only causes an unsightly appearance due to the opaqueness of the thick resin, but there is a distinct tendency for these thick areas to develop minute fractures which permit the liquid methyl-methacrylate to enter the core. A second item worthy of mention is the advisability of checking and re-

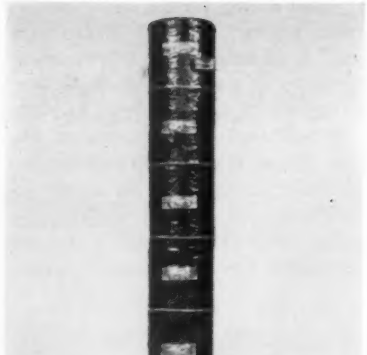


FIG. 3 — CORE PREPARED FOR CASTING IN LUCITE COMPLETE WITH ELECTRODES, PRESSURE RINGS, CENTERING BLOCKS, AND A SEALING COAT OF BAKER RESIN

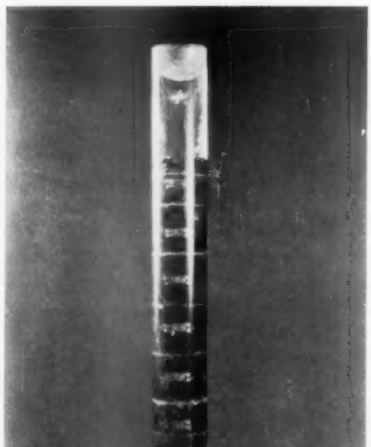


FIG. 4 — LUCITE CASTING AS IT COMES FROM MOLD

checking this sealer coat for pin-hole imperfections, since even the slightest break will permit the pressurized monomer to permeate the pores of the core.

The Baker resin sealing-coat is thoroughly polymerized at 70°C. When this is accomplished, the core is ready for embedment in Lucite and appears as shown in Fig. 3. The ragged appearance of the salt rings at the lower end of the core shown in Fig. 4, in contrast to that of Fig. 3, is caused by thick areas of opaque sealing resin. Fortunately in this case no cracking of the resin occurred, and a successful mount resulted.

The molding of the Lucite sheath is accomplished in a cylindrical mold of suitable dimensions for the core in question. Cores of 2 in. diameter have been successfully molded in a 2⅝ in. diameter mold. However, cores molded with a ½ in. radial sheath have proved to have more satisfactory aging characteristics than those molded in the smaller barrel. Both steel and aluminum have been used as molding barrels. Zinc stearate is applied to the aluminum mold, as a releasing agent, as a dry powder or as a 15% naphtha suspension with 1% mineral oil. The steel barrel used had a mirror surface, and no mold release was necessary.

The molding procedure is deceptively simple. When the core has been prepared and completely sealed, as described above, centering guides are fixed to the core near the top and bottom as shown in Fig. 3. These consist of small blocks of Lucite of such size that when three are wired to the core circumferentially equidistant they will just permit the core to enter the molding cylinder, thus insuring a core centered in the resultant plastic sheath.

The apparatus used for monomer-polymer dough molding consists of three essential items: (1) A constant-temperature, circulating water bath held at 70°C. (2) The cylinder in which the Lucite is molded, and means of slowly lowering this mold into the water bath. (3) A means of applying pressure to the monomer-polymer dough. For the last a nitrogen bottle serves well. 300 psig being sufficient pressure. For item (1) it has been found suitable to use a cylindrical bath 5 ft deep and 2 ft in diameter equipped with immersion heaters and a circulating pump. Item (2) has already been mentioned. Flanges are provided on the ends of the molding cylinders to which are bolted suitably gasketed end plates. The top end plate is provided with a ⅛ in. pipe fitting to permit application of the nitrogen pressure.

When the above equipment is in readiness, the monomer-polymer dough may be mixed. When calculating the volume of ingredients required, it is well to mix enough excess to permit approxi-

mately four to six inches of solid Lucite to cover the molded core. Values used in these calculations are: 1.18 the density of the finished polymer, 0.95 the density of the monomer, and 0.73 as the effective density of the polymer granules. The last is simply a rough figure used to facilitate volumetric measurement of the ingredients. The dough is mixed using a weight ratio of 60% polymer-40% monomer. Best results are obtained by following the mixing directions outlined in reference 2; pouring the polymer granules into the monomer accompanied by constant stirring. This must be performed in a hood with adequate ventilation. The mixture is stirred until a "no-settling" state is reached or until the mixture tends to drop from the stirring rod rather than flow. At this stage it is quickly transferred to the molding cylinder, the core complete with centering blocks is dropped into the mold, the top end plate is bolted in place, and nitrogen gas at a pressure of 300 psi is applied. The mold is lowered into the bath until the bottom is just 1 in. under the surface of the 70° water. The mold cylinder is equipped with a tight fitting coil of copper tubing through which cold water circulates. This coil is placed just above the surface of the immersion bath to insure localization of the applied heat. The mold is held in this position for 30 minutes and is then lowered 1 in., simultaneously raising the cooling coil so that it clears the bath surface. This rate of lowering is held at one inch per 30 minutes for the first 4 in. The remainder of the mold is immersed, at the rate of 1 in. every 20 minutes, until the entire length of the Lucite casting is being subjected to the 70°C. temperature. The temperature is held at 70°C. for two to three hours, then the bath is permitted to slowly cool to room temperature before removing the molding cylinder.

Fig. 4 shows the casting as it appears when removed from the molding cylinder. Note the solid Lucite above the core with the concavity evident in the top surface of the casting. This is a result of shrinkage of the monomer as polymerization occurs. The Lucite below the core is the result of placing a 1 in. to 3 in. block of solid Lucite in the molding cylinder before adding the dough mixture. Whether it is essential or not is debatble. Suffice to say better results have been obtained by using such a block.

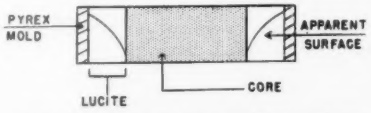
Inasmuch as the above described procedure of slowly lowering the molding cylinder into the heating bath and using a cooling coil to localize the heat is a bit cumbersome, a brief discussion of the reasons for so doing may be appropriate. Little attempt will be made to justify the technique on theoretical grounds. Most of the know-how came the hard way, by trial and error. However, note that the methyl-methacrylate monomer shrinks approximately 20% upon polymerization, and the reaction is exothermic to the extent of 80 to 85 calories per gram.

Early attempts to cast cores using the dough technique resulted in spectacular failures. The surface of the core would be partially or wholly covered with blisters, leaving considerable space between Lucite and core which eventually would permit by-passing of fluids and destroy the usefulness of the core.

On the hypothesis that these blisters were due to the polymerization shrinkage, the problem was met by simply trying to localize the volumetric change at some surface other than that of the Lucite-core contact. The first approach using complete initial immersion was to simply increase the applied pressure in the hope that mobile dough would be forced down into areas of shrinkage occurring within the mix. This was not realized. The rate of immersion was varied in an effort to polymerize the resin at the bottom of the mold first, the unpolymerized, still-mobile dough above flowing down to occupy the shrinkage volume. Intermittent success obtained. The first concrete step toward a consistently successful technique came with the use of a 3-in. OD x ¼-in. wall Pyrex glass cylinder as a molding vessel. The casting technique was carried out several times in this cylinder and the polymerization visually observed from behind a safety shield of sheet Lucite. These observations determined the rate of immersion now in use.

When the glass mold was wholly immersed in one stage the mix cleared (became transparent) first at the bottom, and the transition zone moved rapidly to the top of the core. As polymerization proceeded blisters could be seen as they developed at the Baker resin-Lucite surface, usually forming first near the bottom of the core and progressively appearing at upper levels. The concavity at the Lucite surface (Fig. 4) was deficient in depth in the case of one stage immersion. Upon cooling of the mold the resultant radial shrinkage of the polymerized resin could be seen to reduce the blistered area between the Baker resin and Lucite. Subsequent dipping of the mold into a hot bath would increase these areas.

Further testing demonstrated that by slowly lowering the mold into the hot bath, the polymerization of the resin could be visually detected by the appearance of a "diffraction surface" roughly the shape of an inverted frustrum of a cone as shown in the accompanying sketch.



APPEARANCE OF POLYMERIZATION ZONE DURING MOUNTING PROCESS

The mix was perfectly clear above and below this surface, and the steepness of its slope could be controlled by the rate of immersion of the mold. The faster the rate of immersion the steeper became the slope. The most beneficial results were realized when the rate of mold immersion was such that the diffraction surface had only a minor slope. These observations led to the use of the immersion rates cited above, as well as the use of the cooling coil and the higher pressures. The cooling coil is used in an effort to maintain the dough above the polymerization zone unpolymerized, hence mobile enough to move down and occupy void space created by polymerization shrinkage.

In addition to the shrinkage blisters, it was not uncommon to find numerous small tear-drop bubbles in the polymerized Lucite. These had apparently originated very close to the core surface, and expanded toward the confining walls of the mold. A tentative explanation was that these were the result of an elemental surge of boiling possibly due to localized overheating near the sand body where the heat of reaction could not be dissipated. This led to the installation of thermo-couple leads in the dough mix on one of the experi-

mental mounts. The maximum temperature recorded in the resin mix was 150°C. The bath used was 80°C. Pressures used up to this time had not exceeded 150 psig. Subsequent pressures were gradually raised to the present figure of 300 psi gauge.

After the core has been removed from the mold it appears as in Fig. 4. The ends are then sawed from the core exposing the sand for flow tests. At this time the presence or absence of the odor of methyl-methacrylate monomer will evaluate the effectiveness of the Baker resin sealer. The core is then fitted with end plates, flow lines, pressure taps, and electrode connections as shown in Fig. 1. The core is now ready for further cleaning and subsequent flow tests.

The mounts are rather sensitive to temperature change, and repeated fluctuation of the ambient temperature over a span of roughly 10°C. tends to destroy the bond between the Lucite and the sealing resin. This effect has not been noticeable on cores having the thicker Lucite coating (½ in.), these cores having been used continuously for two years with no apparent deterioration of the bond. Cores mounted in the above manner, and fitted as shown in Fig. 1 have been used with pressures up to 100 psi. Fluids commonly used are those to which Lucite is inert; hydrocarbons containing no aromatics or unsaturates, aqueous solutions of common salts, and occasionally dilute acid solutions.

References

1. A product of E. I. du Pont de Nemours and Company, Inc., Arlington, New Jersey.
2. Molding of Methyl-Methacrylate Monomer-Polymer Doughs — Technical Service Report No. 3, February 1, 1945, E. I. du Pont de Nemours and Company, Inc., Arlington, New Jersey.
3. Baker Casting Resin, Type No. 100972; a product of Baker Oil Tools, Inc., 6000 South Boyle Ave., Los Angeles, California.
4. E. I. du Pont de Nemours and Company, Inc., op. cit.
5. Baker Oil Tools, Inc., op. cit. * * *

Mississippi Sub Section Activities

By Sam J. Poythress, Jr.

The featured speaker for the July 26 meeting of the Sub Section, held on the roof of the Eola Hotel in Natchez, was Arthur E. Herrald, Mississippi division manager for Schlumberger Well Surveying Corp. in Jackson, Miss. He was introduced by Leo Hines, California Co. in Natchez, and gave the 44 members present an informative discussion of "Electric Log Interpretation in Mississippi."

Herrald stated that log interpretation in Mississippi is basically no different from interpretation elsewhere, although in Mississippi some oil fields have been passed up due to certain characteristics of the sands. These are the briny connate waters found in Mississippi, and the presence of a large percentage of finely divided material in the sands.

A review of the logging process and logging interpretation was made. Herrald presented as an example the log from a discovery well in a new field where a non-productive sand adjacent to a productive sand seemed, upon casual examination, to be a better sand. He then showed how proper long interpretation revealed the productive sand to be productive, and the other to be non-productive.

Chairman R. E. France presided at the business session, and announced that the next meeting will be held in September in Jackson with David C. Harrell as program chairman.

Mid-Continent Section Activities

By John P. Hammond

A joint luncheon with the Engineers Club of Tulsa is being arranged for Monday, September 12 to open the fall season. Featured speaker for the occasion will be L. E. Young, president of AIME. Because of his well-known interest in engineering students, it is planned to invite the Univ. of Tulsa engineering group to attend the joint luncheon.

Plans are being made for President Young to tour some of the petroleum research facilities in the vicinity of Tulsa during his visit here.

The annual barbecue and outdoor stag party of the Section, often referred to as the Annual Round-up, will be held at James N. McGirl's suburban home near Skiatook.

Victor H. Wilhelm Dies in Long Beach

Captain Victor H. Wilhelm, USNR, died at Long Beach, California, Naval Hospital on July 7. He was graduated as a geologist and mining engineer from Stanford Univ. in 1907 and followed mining and oil all his life.

In 1941 he was called to duty as Lieutenant Commander in the Naval Reserve in the Office of Inspector Naval Petroleum Reserves in California. He remained on active duty at the close of the war and had been the Inspector of Naval Petroleum Reserves in California since 1944.

Pacific Petroleum Chapter Activities

By Frank Parker

On June 27 the Technology Forum heard Russell Wade discuss the Miocene West Townlot Block pool of the Dominguez field. Wade, a production engineer for Union Oil Co. at Compton, California, is a native of Los Angeles and a graduate of the Univ. of Southern California in 1941, where he also received an M.S. degree in petroleum engineering.

The pool discussed was discovered in April, 1941, by Union Oil Co.'s "Austin" No. 7, some eighteen years after the discovery of the Dominguez field and eight years after the discovery of the 7th zone, its stratigraphic correlative. The pool lies on the tip of the west plunge of the anticline forming the field and is separated by a pressure barrier, presumably a fault, from the remainder of the 7th zone producing Area. Only 50 ft of the 7th zone is productive here, and that is divided in this local area into a lower, Pongratz sand, and several relatively unimportant thin upper, C. R., sands. The Pongratz sand is a nearly uniform blanket sand averaging 36 ft in thickness extending over the entire Townlot area of 79 acres. The second well into this sand was completed in August, 1941, for 1300 B/D and touched off a drilling boom resulting in the drilling of 19 wells and five dry edge wells. A sharply increasing GOR accompanied the intensive drilling and production. The peak production reached 4000 B/D, a rate sufficient to have produced the entire recoverable oil volume in five months.

The wells were completed with slotted liners in the Pongratz sand and some wells were later gun perforated opposite the C. R. sands. The Pongratz sand is clean and uniform, with an average air permeability of about 200 md, a permeability variation of .47 (equivalent to 1.8 standard deviation), and a P.I. of .45 to 1.4 B/D psi. The original oil in place is calculated at 3,800,000 bbl. The oil-water interface was originally at 7200 ft sub-sea, with the crest of the pool at 7090 ft sub-sea. The oil-water interface appears to have been ten ft lower on the south margin of the field. The original temperature was 210°F, the pressure 2740 psi (subnormal for the depth), the bubble point GOR 600 cu ft/bbl and the gravity 32°. Based upon the published Sage and Lacy PVT data, calculations indicate a formation volume factor of 1.36 and a bubble point of 2760 psi which is in good agreement with the observed original BHP.

The C. R. sand on the north flank totals some 12 ft with an air permeability of 80 md and variation of .71, and on the south flank totals about 24 ft with a permeability of 170 md and variation of .59. The influence of this sand, however, on the production history and characteristics is inconsequential.

The difference in drive or control between the Townlot pool, as compared to that of the stratigraphically equivalent zone of the adjacent portion of the field was demonstrated by the pressure histories. The former pool showed a very rapid decline from initial of 2700 psi to 650 psi in one year, then a gradual rise to 1600 psi to the end of 1948. The adjacent area of the 7th zone

(Continued on Page 9)

AT JUNE 27 FORUM MEETING

Left to right: Gerald B. Thomas, Signal Oil and Gas Co.; N. van Wingen, Petroleum Technologists, Inc.; Paul Mallory, Oil Properties Consultants, Inc.; William F. Cerini, Union Oil Co.

Left to right: Andy Smith, Seaboard Oil Co.; Russell Wade, Union Oil Co., speaker of the evening; Robert R. Hawkins, Signal Oil and Gas Co.

J. E. BRANTLY

Plans Progress for Branch Organization in Rockies

A discussion of organizational plans and possibly on election of officers for a Rocky Mountain Chapter of the Petroleum Branch will take place in Casper, Wyoming on September 13 at a meeting of the Wyoming Local Section. The principal speaker for the meeting will be J. E. Brantly, president of Drilling and Exploration Co., Dallas, who will discuss objectively the shortcomings of present drilling equipment and suggest further exploitation of steam and electric possibilities.

The plans for a Branch organization in the Rockies are the result of favorable expressions from a number of members in Casper and Denver. Preliminary plans, which have been furthered by George Goodin, Petroleum Information, Inc., Casper; E. F. Stratton, Schlumberger Well Surveying Corp., Denver; and Fred Clement, Continental Oil Co., Denver, contemplate the formal organization of groups in both Denver and Casper, which together will compose the Rocky Mountain Chapter.

This plan has precedent in the first and only other (Pacific Petroleum) Chapter of the Branch, which sponsors separate activities in Los Angeles, south of Los Angeles (Junior Group), and the San Joaquin Valley.

Permian Basin Section Activities

By Tom W. Flewharty

Lewis E. Young, of Pittsburgh, Pa., president of the AIME, was the guest of the Permian Basin Section at its June 20 meeting in Midland's Hotel Scharbauer.

Dowell Incorporated was host at a cocktail party given in President Young's honor at the Scharbauer before the meeting. Approximately 175 members and visitors of the Section attended and heard him discuss "Technical Assistance and the ECA Program."

In his address, Young praised Paul Hoffman and the work of the Economic Cooperation Administration. Hoffman, he said, deserves much credit in averting war with Russia up to the present. By improving the industrial capacity of the Eureopean Democracies, the ECA would continue to be a strong force in world peace.

Young said that in his opinion the rebuilding of foreign countries industrially would pose no great threat to our own foreign trade. The reasons why it would not were: American know-how, cooperation of labor and management, venture capital, and American experience. In elaborating on the cooperation of labor and management, he said that although at times it might seem that this cooperation was small, in comparison with other countries it was very great.

On the facing page is a series of photographs taken at the party preceding the meeting and at the meeting.

1 — **Left to right: Paul Fitzgerald, Dowell Incorporated, Tulsa; John McCutchin, McCutchin Drilling and Production Co., Midland; W. L. Crothers Local Executive Committee) Humble Oil and Ref. Co., Midland.**

2 — **Left to right: Craig Evans, Humble Oil and Ref. Co., Colorado City; Sid Leach, Humble Oil and Refining Co., Wink, Texas; A. J. Shaw, Humble Oil and Refining Co., Forey, Texas.**

3 — **Left to right: F. W. Ficklin, L. B. Holly, and Harold Kendirck, all Texas Tech student associates, Lubbock.**

4 — **Left to right: Cliff Matthews, The Western Co., Midland; Bill Remy, Continental Oil Co., Midland; Jack Williamson, Continental Oil Co., North Cowden.**

5 — **President Young addressing Permian Basin Section June 20. That's Tom C. Frick, Permian Basin Section Chairman, in the background.**

6 — **Left to right: Alden S. Donnelly, Honolulu Oil Corp., Midland; H. E. Chiles, Jr., The Western Co., Midland; John F. Younger, The Western Co., Midland.**

7 — **Left right: G. B. Evans, Honolulu Oil Corp., Sundown; T. C. Williams, Honolulu Oil Corp., Denver City; Blackie Craddock, Honolulu Oil Corp., Sundown; Dutch Bowersock, Dowell Incorporated, Midland; Dean Murray, The Texas Co., Midland.**

8 — **W. L. Ducker, chairman of petroleum engineering department, Texas Tech.**

9 — **Left to right: Alden S. Donnelly, Honolulu Oil Corp., Midland; William N. Little, (Section Program Chairman), Tide Water Associated Oil Corp., Midland; Tom C. Frick, Atlantic Ref. Co., Midland; Lewis E. Young, president of AIME, Pittsburgh, Pa.; Bert R. Haigh, University Lands, Midland.**

10 — **Left to right: E. L. Perkins, Argo Oil Corp., Midland; J. L. Rike, Humble Oil and Ref. Co., Odessa; Dave Kister, The Ohio Oil Co., Midland; Aaron Cawley, Honolulu Oil Co., Denver City; John Gould, Honolulu Oil Co., Sundown; G. B. Evans, Honolulu Oil Corp., Sundown.**

11 — **Left to right: M. L. Stirling, Dowell Incorporated, Tulsa; J. L. Nichols, Stanolind Oil and Gas Co., Fort Worth; Tom B. Campbell, Stanolind Oil and Gas Co., Midland; Dayton Kitley, The Ohio Oil Co., Hobbs, N. M.**

12 — **Left to right: Russell Smith, Mid-Continent Plastic; Phil Wogan, Products Research Service, Inc.; Bill Crenshaw, American Inspection Service, Midland.**

13 — **Left to right: Burton Atkinson, (Chairman Permian Basin Section for 1948, Vice-Chairman, National Membership Committee, Local Section Executive Committee), Humble Oil and Ref. Co., Midland; E. B. Armstrong, (Chairman Permian Basin Section for 1947), Honolulu Oil Corporation.**

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Pacific Chapter Activities

(Continued from Page 4)

showed a continuous and much less rapid decline from the same initial to 200 psi at the end of 1948, the contrast being due to an active water drive in the adjacent area of the field. It is interesting to note that water influx-pressure relation could be very satisfactorily correlated with values calculated by Hurst's method.

The Townlot pool history showed a short period of depletion type production, a short period of gas drive and then a relatively long period of water drive. This was thoroughly demonstrated by a comparison of the production histories of four wells located in a line extending from the north edge of the pool to a point midway between the crest of the structure and the south edge of the pool. The well to the north and very close to edge water showed the high production rate and quick decline of the depletion type, the water having flooded the well before other effects could be felt. The next well south of this showed a short period of leveling off after the rapid depletion type of decline and before abandonment because of high water cut. The third well showed the high peak and rapid decline of depletion mechanism, a leveling off and then an increase to another, although much lower and broader peak, as the full effect of first, banked up gas, then water drive was felt. The fourth well, at the southern end of the line, completed somewhat later, showed little flush production of the depletion type, although some slight decline from the initial could be seen. Its production rose to a peak nearly two years later, as the water front approached it, and the formerly reduced pressures were again built up. For the field as a whole, it is estimated about 23 per cent of the oil in place was produced by the depletion mechanism and 19 per cent by the water drive.

A pressure sink was developed early in the history of the pool in the area of intensive drilling. As water encroached from the north and west, this pressure sink migrated southerly toward wells not yet flooded out. The minimum value of pressure in the sink was about 600 psi early in 1942, but this rose until the low of the pool was 1200 psi in January of 1944. As wells approached 90 per cent cut and abandonment, toward the end of 1948, the pressure reached 1600 psi.

The GOR's declined while well pressures were high. This is ascribed to the displacement of the local gas-oil interface by an oil front which was in turn followed by water. High, but essentially meaningless GOR's followed as the water production increased and the oil production became negligible.

Successive iso-cut maps show the progressive sweep of the water. More revealing, however, are a series of isochronic maps showing the times at which the various wells reached a specific water cut. This set of maps showed clearly the rapid water incursion from the north, the "high" changing location from the crest of the structure to a more southerly and lower position with each increase of cut portrayed.

The pool is now essentially abandoned with a total recovery of 1,650,000 bbl, amounting to 428bbl/acre-ft, of which 234 bbl/acre-ft was obtained by the depletion process and 194 bbl/acre-ft by water drive.

From observed production and drawdown, the average effective permeability appears to be 1 and 2 md. The calculated permeability to the fluids under reservoir conditions is 11 md for the oil and 6 md for the water; the oil under reservoir conditions is considered to have a viscosity of 0.85 centipoise, the water 0.28, and the mobility ratio of the fluids is 0.55. As calculated from this rather favorable mobility ratio, vertical coverage of the water sweep is 94 per cent. Lateral coverage is estimated at 80 per cent. The recovery of oil as estimated by the methods of Dykstra and Parsons would be 42 per cent and the actual recovery approximately 43 per cent, a remarkable agreement.

Announcement

A number of extra copies of the maps furnished at the Oakridge-Ojai field trip are available. They can be obtained from Frank S. Parker by calling at 11th Floor, 811 West 7th Street, or by mail, by enclosing 10 cents in stamps.

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Personals

(Continued from Page 6)

William H. Burke of Tulsa is one of the five members of the Executive Committee of the Mid - Continent Section.

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N. VAN WINGEN recently resigned his position as professor of petroleum engineering in the Univ. of Oklahoma to become vice president of Petroleum Technologists, Inc. of Montebello, Calif. The firm has been recently established and will specialize in core analysis. NORRIS JOHNSTON, formerly affiliated with general Petroleum Corp., is president of the new firm.

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GRAYDON H. LAUGHBAUM, formerly district geologist for the Sinclair Oil and Gas Co. in Oklahoma City, has been made research geologist for the Central Division, and has opened an office at 1101 Colcord Building, Oklahoma City.

+

MORRIS M. LEIGHTON, chief of the Illinois State Geological Survey was recently elected president of the Society of Economic Geologists. He completed 25 years as chief of the Illinois Survey last year.

+

ROBERT W. SNEED is Eastman Oil Well Survey Company's new district sales manager for Oklahoma. Sneed started with the company as a sales and service engineer two years ago.

* * *

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 601 Continental Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened, and no fees are involved.

Replies to the personnel coded M-449 and positions coded Y1497 and Y2378 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦ Petroleum engineer with geology degree wants to locate a new connection, preferably with a major company in the Mid-Continent area. Will accept an assignment in the Rocky Mountain area. Have supervised the drilling and completion of several hundred wells from Kansas to the Louisiana Gulf area. Have had several years experience as a valuation and reserve engineer in division office. Have also planned and executed several successful water floods. Code 108.

♦ Geologist, B.S., M.S., recent graduate, single, age 24, desires position with oil company, mining company or geophysical establishment. Research or field work. Will go anywhere in U. S. or Canada. M-449.

POSITIONS

♦ Independent drilling and producing company operating extensively in the United States and abroad requires graduate engineers or geologists with knowledge of drilling to serve in Latin America, south of the equator. Salaries excellent. Married men preferred. Code 509.

♦ Assistant Professor to take charge of a newly created curriculum in petroleum production engineering in a southeastern university. Salary $3900 for nine months. Possibility of $900 more for summer work in research. Reply by letter stating personal data, education, and experience. Y2378. * * *

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Producing at End of 1948; Showing Flowing and Artificial Lift.

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Book Reviews

Bibliography

By Arthur D. Little, Inc., Cambridge, Mass.

A selected bibliography on industrial uses of radioactive materials has been prepared and is being offered without charge by Arthur D. Little, Inc. The bibliography contains 177 titles, of which 44 are from petroleum engineering.

Principles of Petroleum Geology

By Cecil G. Lalicker. Appleton-Century-Crafts, 1949; p. 377 and XII.

Both author and publishers are to be congratulated on the *Principles of Petroleum Geology*. Here the salient facts on origin, accumulation, migration of, and exploration for oil and natural gas, as well as numerous examples of pools are arranged according to a tectonic rather than the usual geographical classification.

Although the chapters on Migration, Reservoirs, and Exploration are not completely adequate, the book is highly recommended as a text for seniors in geology or geological engineering.

The chapters on Recovery and Valuation are considered especially timely. Brief sections on geographic and stratigraphic occurrence adds to the utility of the work, and a table of world reserves is another attractive feature.

A World Tour in Oil

By Dr. Alfred M. Leeston, Southern Methodist Univ., Dallas, Texas; 35 p., illus., maps; heavy cover binding. 50c.

Only 35 pages, but each packed with interesting information, is this tour of the world's oil fields by Dr. Alfred M. Leeston, who has an outstanding background in foreign trade and affairs. Modern economic geography superimposed on a background of oil history and legend makes every page worthwhile reading.

The book takes the reader on tour of 31 oil producing countries and briefly surveys their economic and social background and political conditions with data, references, and quotations. Basic statistics and maps make the book a handy reference, and suggested reading material facilitates further and more detailed study.

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Natural Gas Engineering, Volume III

Mineral Industries Extension Services, School of Mineral Industries. By M. M. Stephens and O. F. Spencer, 2 ed. Pennsylvania State College, State College, Pa., 1949. 565 p., illus., diagrs., charts, maps, tables, 9¼ x 6¼ in., cloth, $4.50.

This volume is the third in a series designed for use by men employed in the natural gas and related industries. Section I covers natural gas economics, measuring properties, gas well completion and operation. Section II deals with gas gathering, compression, and transmission; Section III, with gas measurement and regulation; and Section IV, with natural gasoline manufacture and cycling. In this second edition much of the material has been revised, and the chapter on liquid fuels has been omitted. * * *

ALL INSTITUTE SECTION

APPEARING IN:
• MINING ENGINEERING
• JOURNAL OF METALS
• JOURNAL OF PETROLEUM TECHNOLOGY

More Students in Mineral Engineering Courses

By WILLIAM B. PLANK AND EDWARD MARTINEZ • HEAD DEPARTMENT OF MINING AND METALLURGICAL ENGINEERING AND ASSISTANT PROFESSOR IN MINING, RESPECTIVELY, LAFAYETTE COLLEGE.

There were 15,028 students enrolled in mineral engineering courses on Dec. 1, 1948, in the United States and Canadian colleges, as revealed by the ninth biennial questionnaire study made by the writers under the auspices of the Mineral Industry Education Division of the AIME. Sixty-four colleges in the United States and eight in Canada are covered by the study.

Every mineral engineering school in both countries is represented in the study and for that reason the data are comparable with former studies. As formerly, the general enrollment figures are included, taken this year from the February, 1949, issue of the *Journal of Engineering Education.*

The combined enrollment of 15,028 mineral engineers in both countries is 16.6 percent larger than the enrollment of 12,892 in 1946-1947. There was an increase of 20 percent in the United States figures, but a decrease of 14 percent in the Canadian figures during this period. These comparisons are shown in Tables 1 and 2.

The current total enrollment of 249,913 engineers of all kinds in the United States and Canadian colleges, shown in the data supplied by the ASEE in Table 3, is 12 percent greater than the 222,557 enrollment in 1946-47. The mineral engineering group of both countries showed a growth of 16.6 percent during the same period. As compared with 1947-48, however, the total engineering enrollment decreased about 1 percent, whereas the mineral engineering enrollment increased 22 percent to an all-time peak, thus maintaining a steady growth that was begun right after the war.

The number of first degrees in engineering conferred in 1946-47, as shown in Table 4, was 19,272 and in 1947-48, 30,018. It has been estimated that this year at least 40,000 engineers will be graduated and probably the same number will graduate next year. This year 2881 mineral engineers in both countries will receive their first degrees and the number will probably be larger next year. Thus it is seen that the deficit in the supply of engineers caused by the war is being met rapidly.

An indication of the possible trend in engineering enrollment can be seen in the decrease in the size of the freshman classes over these two years as shown in Table 3. In 1946-47, the total number of freshman engineers of all kinds in the United States and Canada was 84,652, whereas this year the group numbers 49,017. This is a decrease of 42 percent. The decrease in the number of mineral engineering freshmen during the same period, however, was from 4933 to 3090, or 37 percent.

Eventually, the decline in veteran enrollment and the lower birth rate during the war, of which these figures are an indication, will materially reduce the size of the engineering student groups of all kinds. S. C. Hollister, of Cornell University, estimates that the number of entering freshman engineers is undergoing a normal readjustment which by 1952-53 will

TABLE 1. MINERAL ENGINEERING STUDENT ENROLLMENT BY COURSES—1948-49, UNITED STATES, 64 SCHOOLS

Course	Freshman	Sophomore	Junior	Senior	Total Undergraduates	Graduate Students	Grand Total	Candidate B.S. Degree
Mining	481	544	517	456	1,998	82	2,080	426
Metallurgy	649	836	1,008	815	3,308	552	3,860	789
Petrol. and Nat. Gas	1,024	1,076	1,151	752	4,003	91	4,094	709
Ceramic	181	284	315	251	1,011	164	1,175	227
Geology	553	611	698	401	2,263	197	2,460	379
Fuels	6	8	9	8	31	16	47	8
Specials	.....	.....	.....	.....	53	.....	53	.....
Totals	2,894	3,339	3,698	2,683	12,867	1,102	13,769	2,538

Revision of a paper read before Mineral Industry Education Division, AIME, San Francisco, Calif., Feb. 14, 1949.

TABLE 2. MINERAL ENGINEERING STUDENT ENROLLMENT BY COURSES—1948-49, CANADA, 8 SCHOOLS

Course	Freshman	Sophomore	Junior	Senior	Total Under-graduates	Graduate Students	Grand Total	Candidate B.S. Degree
Mining	99	112	163	178	552	0	552	172
Metallurgy	43	68	99	77	287	11	298	77
Petrol. and Nat. Gas	13	23	17	0	53	0	53	0
Ceramics	5	13	8	11	37	2	39	11
Geology	36	65	76	83	260	57	317	83
Totals	196	281	363	349	1,189	70	1,259	343

TABLE 3. ENGINEERING ENROLLMENT BY CLASSES AND COURSES—1948-49, 151 UNITED STATES AND 6 CANADIAN SCHOOLS

Course	Freshman	Sophomore	Junior	Senior	5th Year and Others	Total Under-graduates	Graduate Students	Grand Total
Mining	427	576	637	527	6	2,173	83	2,256
Metallurgy	493	819	1,058	871	127	3,368	687	4,055
Petrol. and Nat. Gas	921	1,186	1,309	916	105	4,437	96	4,533
Ceramics	161	264	319	247	95	1,086	120	1,206
Total Mineral Engineers[1] U.S. and Canada	2,002	2,845	3,323	2,561	333	11,064	986	12,050
Chemical	3,722	5,095	5,955	4,784	1,692	21,248	2,371	23,619
Civil	5,522	8,139	9,483	7,113	1,541	31,798	2,063	33,861
Mechanical	7,725	12,446	15,390	12,093	3,453	51,107	2,535	53,642
Electrical	7,416	11,830	15,725	11,440	3,496	49,907	3,867	53,774
Other Engineers	19,080	12,855	11,921	9,280	8,912	62,048	3,801	65,849
In Extension Centers	3,550	1,869	730	514	455	7,118	.....	7,118
Total Engineers U. S. and Canada	49,017	55,079	62,527	47,785	19,882	234,290[2]	15,623	249,913
Veterans, U. S. and Canada	15,282	28,011	42,959	33,969	12,183	132,394	5,880	138,274

[1] Geological and Fuel Engineers included in "Other Engineers".
[2] Includes 1210 women.

TABLE 5. ENGINEERING STUDENT ENROLLMENT BY COURSES—UNDERGRADUATES AND GRADUATES—1940-41 TO 1948-49

	(1) 1940-41	(1) 1944-45	(1) 1946-47	(1) 1947-48	(2) 1948-49	(3) 1948-49
Mining	1,978	224	2,302	2,459	2,256	2,632
Metallurgy	2,450	472	3,179	4,121	4,055	4,158
Petrol. and Nat. Gas	2,877	376	3,048	4,665	4,533	4,147
Ceramics	843	190	940	1,108	1,206	1,214
Geology	792	?	?	?	?	2,777
Fuels	44	?	?	?	?	47
Specials	149	?	?	?	?	53
Total Mineral Engineers: United States	9,133	.....	.....	.....	.....	13,769
Canada	.....	.....	.....	.....	.....	1,259
U. S. and Canada	.....	1,262	9,469	12,353	12,050	15,028
Chemical	.....	5,082	23,600	26,972	23,619	.....
Civil	.....	3,537	30,079	31,849	33,861	.....
Mechanical	.....	6,965	44,403	56,551	53,642	.....
Electrical	.....	5,934	38,963	56,406	53,774	.....
Others	.....	18,852	66,475	68,117	72,969	.....
Total Engineers	114,116	41,632	222,557*	252,250	249,913	.....

[1] Mining & Metallurgy, April 1948, U. S. and Canada.
[2] Journal of Engineering Education, Feb. 1949, U. S. and Canada.
[3] Study of Mineral Education Division, AIME, Dec. 1, 1948.
* Includes 9568 Canadian undergraduate students, unclassified.

bring the number of graduations down to the prewar gradient of steady upward growth.[1]

The percentage of veterans studying engineering in both countries dropped from 57 percent of the total last year to 55 percent this year, This year 31 percent of the freshman engineers are veterans compared to 42 percent last year.

Among the mineral engineers in the United States, the petroleum and natural gas engineers maintain their position as the largest group, with

TABLE 4. FIRST DEGREES CONFERRED, ALL ENGINEERS, UNITED STATES AND CANADA

1942-43	14,714
1943-44	11,155
1944-45	4,724
1945-46	8,219
1946-47	19,272
1947-48	30,018

4094 students. They are followed closely, however, by the metallurgists with 3860 students. Next in rank are the geological engineers and mining geologists, listed under the title "Geology" in the tables, with 2460 students. The mining engineers rank fourth, numbering 2080 students, and the ceramic engineers are fifth in rank, with 1052 students.

Of significance to employers of mineral engineers in the United States is the fact that there are available for positions in the mineral industries only 2538 bachelors and about 500 graduates from this year's class. As usual, however, not all of these men will be available for jobs since a number will go into teaching, graduate schools, or other industries.

Employment opportunities for this year's mineral engineering graduates generally have been good but with a slower demand for men in the industries affected by the present slowing up of production. Demand for mining engineers in the east is reported to be better than elsewhere especially by the iron ore and the coal industries.

The employment situation for other engineers who graduated this year has not been so favorable. Deans of engineering schools say that all graduates will be placed but not as rapidly as in recent years. It has been estimated that out of the 40,000 engineers who graduated this year only 24,000 will be absorbed by industry, leaving a surplus of 16,000. It is believed that of the many factors that may cause a sharp upward trend in engineering employment of all kinds are the wider use of technology, the use of engineers in other professions, and above all, the increasing number of engineering problems involved in winning from the earth, the sea, and the air, the raw mineral materials upon which our highly industrialized civilization depends.

[1] Postwar Engineering Enrollment, Journal of Engineering Education, March, 1949.

TABLE 6. DISTRIBUTION OF GRADUATE STUDENTS IN MINERAL ENGINEERING—UNITED STATES, 1933-34 TO 1948-49

	1933-1934	1934-1935	1936-1937	1938-1939	1940-1941	1942-1943	1946-1947	1948-1949
Mining	40	55	49	44	44	20	70	82
Metallurgy	116	93	131	172	215	137	470	552
Petrol and Nat. Gas	18	29	58	43	75	27	197	91
Ceramics	19	36	48	64	50	19	138	164
Geology	46	62	34	86	127	9	127	197
Fuels	4	10	18	6	9	10	16	16
Totals	243	285	338	415	520	222	1,008	1,102

Data from Mineral Industry Education Division, AIME, studies.

Directory of Mineral Engineering Schools in the United States and Canada

**Accredited by ECPD, October, 1948*

The name and address of the school are given, followed by the length of the regular undergraduate curriculum, the degree granted, types of courses given, and the name of the man in charge. This covers only work for the first or Bachelor degree in each case. School catalogs should be consulted for details.

The following abbreviations are used:

A. Arts
B. Bachelor
Cer. Ceramics or Ceramic
E. Engineer or Engineering
Eng. Engineering or Engineer
Eco. Economic
Geol. Geologist, Geological, or Geology
M. Mines or Mining
Met. Metallurgy or Metallurgical
Min. Mineral
Mng. Mining
M.S. Master of Science
Pet. Petroleum
Ref. Refining
S. Science
Tech. Technology or Technical

UNITED STATES

University of Alabama, University, Ala. 4-yr. B.S. in: (1) *Mng. Eng., (2) Met. Eng., (3) Met., (4) Cer., (5) Pet. Tech. James R. Cudworth, dean; J. W. Stewart, head, School of Mines; T. N. McVay, head, Dept. of Ceramics.

University of Alaska, College, Alaska. 4-yr. or 5-yr. B.S. major in: (1) *Mng. Eng., (2) *Mng. Eng., Geol. option, (3) *Mng. Eng., Met. option. Richard C. Ragle, head, Dept. of Geology; Earl H. Beistline, head, Dept. of Min. & Met.

University of Arizona, Tucson, Ariz. 4-yr. B.S. in: (1) *Mng. Eng., (2) Met. Eng., (3) Mng. Geol. (4) Geol. T. G. Chapman, dean, College of Mines.

Polytechnic Institute of Brooklyn, Brooklyn 2, N. Y. 4-yr. B.Met.E. Otto H. Henry, professor of Metallurgical Engineering.

University of California, Berkeley, Calif. 4-yr. degrees in: (1) *Mng. Eng., (2) *Met., (3) *Pet. Eng., (4) Mineral Exploration. Lester C. Uren, chairman, Division of Mineral Technology.

Carnegie Institute of Technology, Pittsburgh, Pa. 4-yr. B.S. in *Met. Eng. Robert F. Mehl, head, Dept. of Metallurgical Engineering.

Case Institute of Technology, Cleveland, Ohio. 4-yr. B.S. in *Met. Eng. K. H. Donaldson, head, Dept. of Metallurgical Engineering.

University of Cincinnati, Cincinnati, Ohio. 5-yr. *Met. Eng. Cooperative. Dr. Roy O. McDuffie, professor of Metallurgy.

Colorado School of Mines, Golden, Colo. 4-yr. (1) *E.M., (2) *Geol. Eng., (3) *Pet. Eng., (4) *Met. Eng., (5) Pet. Ref. Eng. Ben H. Parker, president.

Columbia University, New York, N. Y. 4 or 5-yr. B.S. in (1) *Mng. Eng., (2) *Met. Eng., (3) Mineral Eng. Philip B. Bucky, prof. of Mining and Exec. Officer of Dept. of Mng., Met. and Min. Eng.

Cornell University, Ithaca, N. Y. 5-yr. B.Met.E. Fred H. Rhodes, director of the School of Chemical & Met. Eng.; S. C. Hollister, dean of the College of Engr.

Drexel Institute of Technology, Philadelphia 4, Pa. 5-yr. (co-operative) B.S. in Met. Eng. A. W. Grosvenor, professor of metallurgy.

Fenn College, Cleveland, Ohio. 4½-yr. cooperative in B. of *Met. Eng. Dr. G. U. Greene, head, Dept. of Metallurgical and Chemical Engineering.

Georgia Institute of Technology, Atlanta, Ga. 4-yr. B. of *Cer. Eng. Lane Mitchell, director, School of Ceramic Engineering.

Harvard University, Cambridge, Mass. Undergraduate instruction in engineering sciences and applied physics, or geological sciences, preparatory to professional study in Graduate School of Engineering in (1) *Physical Met., or in Division of Geological Sciences of the Graduate School of Arts and Sciences in (2) Min. Geol., (3) Pet. Geol., (4) Geophysics; or in the Dept. of Engineering Sciences and Applied Physics of the Graduate School of Arts and Sciences. Marland P. Billings, chairman, Division of Geological Sciences.

University of Idaho, Moscow, Idaho. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) Geol., (4) *Geol. Eng. A. W. Fahrenwald, dean, School of Mines.

Illinois Institute of Technology, Chicago 16, Ill. 4-yr. B.S. in Met. Eng. Otto Zmeskal, director, Dept. of Metallurgical Engineering.

University of Illinois, Urbana, Ill. 4-yr. B.S. in: (1) *Cer. Eng., (2) *Met. Eng., (3) *Mng. Eng. H. L. Walker, head, Dept. of Mining and Metallurgical Engineering; A. I. Andrews, head, Dept. of Ceramic Engineering; George W. White, head of Dept. of Geology.

Iowa State College, Ames, Iowa. 4-yr. B.S. in (1) *Cer. Eng., (2) Mng. Eng. G. L. Bridger, head, Dept. of Chemical and Mining Engineering; C. M. Dodd, head, Dept. of Ceramic Engineering.

University of Kansas, Lawrence, Kans. 4-yr. B.S. in: (1) Geol. Eng., (2) Met. Eng., (3) *Min. Eng., (4) Pet. Eng. R. M. Dreyer, Chm., Dept. of Geol. & Geological Eng.; K. E. Rose, Chm., Dept. of Mng. & Met. Eng.; and C. F. Weinaug, Chm., Dept. of Pet. Eng.

University of Kentucky, Lexington, Ky. 4-yr. B.S. in: (1) *Met. Eng., (2) Mng. Eng. C. S. Crouse, head, Dept. of Mining and Metallurgical Engineering.

Lafayette College, Easton, Pa. 4-yr. B.S. in: (1) *Met. Eng., (2) *Mng. Eng. W. B. Plank, head, Dept. of Mining and Metallurgical Engineering.

Lehigh University, Bethlehem, Pa. 4-yr. B.S. in: (1) *Mng. Eng., (2) Mng. Eng., Eng. Geophysics option, (3) *Met. Eng. A. C. Callen, head, Dept. of Mining Engineering: Gilbert E. Doan, head, Dept. of Metallurgical Engineering.

Louisiana Polytechnic Institute, Ruston, La. 4-yr. curriculum in Pet. Eng. Roy T. Sessums, dean, School of Engineering.

Louisiana State University, Baton Rouge, La. 4-yr. B.S. in: (1) *Pet. Eng., (2) Pet. Geol. Henry V. Howe, director. School of Geology.

Massachusetts Institute of Technology, Cambridge, Mass. 4-yr. S.B. in *Metallurgy. John Chipman, head, Dept. of Metallurgy.

Michigan College of Mining and Technology, Houghton, Mich. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) Geol. Eng. Grover C. Dillman, president.

Michigan State College, East Lansing, Mich. 4-yr. B.S. in Met. Eng. L. G. Miller, dean of Engr.; R. L. Sweet, Chm., Met. Eng.

University of Michigan, Ann Arbor, Mich. 4-yr. B.S.E. *(Met.). George G. Brown, chairman, Dept. of Chemical and Metallurgical Engineering.

University of Minnesota, Minneapolis, Minn. 5-yr. (1) *B. Mng. Eng., (2) B. Geol. Eng., (3) *B. Pet. Eng., (4) *B. Met. Eng. T. L. Joseph, dean, School of Mines and Metallurgy.

Missouri School of Mines and Metallurgy, Rolla, Mo. 4-yr. B.S. in: (1) *Mng. Eng. with options in (a) Mng. Geol., (b) *Pet. Production; (2) *Met., (3) *Cer. Eng., (4) B.S., with major in Geol., Cer., or Met. B.S. in Chemical Eng. for those specializing in Pet. Refining. Curtis L. Wilson, dean.

Montana School of Mines, Butte, Mont. 4-yr. B. S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) *Geol. Eng., (4) Pet. Eng. Francis A. Thomson, president.

University of Nevada, Reno, Nev. 4-yr. B.S. in: (1) *Mng. Eng. (2) Met. Eng. (3) Geol. Eng. Jay A. Carpenter, director, Mackay School of Mines.

New Mexico School of Mines, Socorro, New Mex., 4-yr. B.S. in: (1) *Mng. Eng., (2) Met. Eng., (3) *Pet. Eng., (4) *Geol. Eng., (5) Geophysics, (6) Chemistry. 5-yr. B.E. in: (1) Geology. E. J. Workman, president.

New York State College of Ceramics, Alfred, N. Y. 4-yr. B.S. in: (1) *General Cer. Tech. and Eng., (2) Glass Tech. J. F. McMahon, Acting Dean.

North Carolina State College of the University of North Carolina, Raleigh, N. C. 4-yr. B. of: (1) *Cer. Eng., (2) Geol. Eng. W. W. Kriegal, professor of ceramic engineering; J. L. Stuckey, professor of geological engineering.

University of North Dakota, Grand Forks, N. Dak. 4-yr. B.S. in *Mng. Eng. L. C. Harrington, Dean, College of Engineering, director, Division of Mines and Mining Experiments.

University of Notre Dame, Notre Dame, Ind. 4-yr. B.S. in *Met. Edward G. Mahin, head, Dept of Metallurgy.

The Ohio State University, Columbus, Ohio, 5-yr. (1) *B. Eng. in Mng. with option in Pet. Eng., (2) B. *Cer. Eng., option in Glass Technology, (3) B. *Met. Eng. H. F. Nold, professor of mine engineering; J. L. Carruthers, head, Dept. of Ceramic Engineering; Mars G. Fontana, head, Dept. of Metallurgy; E. V. O'Rourke, professor of petroleum engineering.

University of Oklahoma, Norman, Okla. 4-yr. B. S. in: (1) Geol. Eng., (2) *Pet. Eng., (3) Natural Gas Eng. W. H. Carson, dean, College of Engineering.

Oregon State College, Corvallis, Oreg. 4-yr. B.S. in Mng. Eng., with options in (1) Mng. Eng., (2) Met. Eng. W. E. Caldwell, professor of mining engineering.

Pennsylvania State College, State College, Pa. 4-yr. B.S. in: (1) Geol. & Mineralogy, (2) Geophysics & Geochemistry, (3) Meteorology, (4) Geography, (5) Mineral Eco., (6) *Mng. Eng., (7) Mineral Preparation Eng., (8) *Pet. & Nat. Gas Eng., (9) Fuel Tech., (10) *Met., (11) *Ceramics, Edward Steidle, dean, School of Mineral Industries.

University of Pennsylvania, Philadelphia 4, Pa. 4-yr. B.S. in Met. Eng. R. M. Brick, director, Dept. of Metallurgy.

University of Pittsburgh, Pittsburgh, Pa. 4-yr. B.S. in: (1) *Mng., (2) *Met. Eng., (3) *Pet. Eng., (4) Geol. Eng. E. A. Holbrook, dean, Schools of Engineering and Mines.

Princeton University, Princeton, N. J. 4-yr. Geol. Eng., with degree B.S. in Eng. Kenneth H. Condit, dean, School of Engineering; W. T. Thom, Jr., chairman, Dept. of Geological Engineering.

Purdue University, West Lafayette, Ind. 4-yr. B.S. in *Met. Eng. G. M. Enos, chairman, Division of Metallurgical Engineering, School of Chemical and Metallurgical Engineering.

Rensselaer Polytechnic Institute, Troy, N. Y. 4-yr. B. *Met. Eng. W. F. Hess, head, Dept. of Metallurgical Engineering.

Rutgers University, New Brunswick, N. J. 4-yr. B.S. in Cer. John H. Koenig, director, Dept. of Ceramics.

South Dakota School of Mines and Technology, Rapid City, S. Dak. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) Geol. Eng. Warren E. Wilson, president.

University of Southern California, Los Angeles, Calif. 4-yr. B.S. in: *Pet. Eng. C. R. Dodson, head, Pet. Eng. Dept., Thomas Clements, head, Dept. of Geology.

Stanford University, Stanford, Calif. 4-yr. B.S. in *Min. Sciences. A. I. Levorsen, dean, School of Mineral Sciences.

Agricultural and Mechanical College of Texas, College Station, Texas. 4-yr. B.S. in *Pet. Eng. Also 5-yr. (1)* B. Pet. Eng., with options in: (a) Production, (b) Geol., (2) *B.S. in Pet. Eng. and Mech. Eng., (3) *B.S. in Pet. Eng. and Geol. Eng. Harold Vance, head, Dept. of Petroleum Engineering.

University of Texas, Austin, Texas. 4-yr. B.S. in *Pet. Eng. H. H. Power, chairman, Dept. of Petroleum Engineering.

University of Texas, College of Mines and Metallurgy, El Paso, Texas. 4-yr. B. S. in Mng. Eng. with options in: (1) *Mng. Eng., (2) Met., (3) *Mng. Geol. Wilson H. Elkins, president; E. M. Thomas, dean of Engineering.

University of Tulsa, Tulsa, Okla. 4-yr. B.S. in: (1) *Pet. Production Eng., (2) *Pet. Refining, (3) Pet. Geol., (4) Geophysical Eng. R. L. Langenheim, dean, College of Petroleum Sciences & Engineering.

University of Utah, Salt Lake City, Utah. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) Geol. Eng. C. J. Christensen, dean, School of Mineral Industries.

Virginia Polytechnic Institute, Blacksburg, Va. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) Geol., (4) *Cer. Eng. E. B. Norris, dean of Engineering.

State College of Washington, Pullman, Wash. 4-yr. B.S. in: (1) Geol., (2) *Mng., (3) *Met. Donald L. Masson, acting director, School of Mines.

University of Washington, Seattle, Wash. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng., (3) *Cer. Eng. Drury A. Pifer, director, School of Mineral Engineering.

Washington University, St. Louis, Mo. 4-yr. B.S. in *Geol. Eng. Lawrence E. Stout, dean, School of Engineering.

West Virginia University, Morgantown, W. Va. 4-yr. B.S. in Mng. Eng., with options in: (1) *Mng. Eng., (2) Oil and Gas Eng. G. R. Spindler, director, School of Mines.

West Virginia Institute of Technology, Montgomery, W. Va. 5-yr. B.S. in Mng. on co-operative system in coal. Edward L. Holt, head, Dept. of Mng. and Geology.

University of Wisconsin, Madison, Wis. 4-yr. B.S. in: (1) *Mng. Eng., (2) *Met. Eng. Geo. J. Barker, chairman, Dept. of Mining and Metallurgy.

Yale University, New Haven, Conn. 4-yr. B. Eng. in *Met. C. H. Mathewson, chairman, Dept. of Metallurgy.

CANADA

University of Alberta, Edmonton, Alta. 4-yr. B.S. in Mng. Eng., with options in: (1) Metal Mng., (2) Coal Mng. K. A. Clark, professor of metallurgy; E. O. Lilge, professor of ore dressing; T. H. Patching, asst. prof. of Mng. Eng.

University of British Columbia, Vancouver, B. C. 5-yr. B. of Applied S. in: (1) Mng. Eng., (2) Met. Eng., (3) Geol. Eng. F. A. Forward, head, Dept. of Mining and Metallurgy; M. Y. Williams, head, Dept. of Geology and Geography.

Laval University, Quebec. 4-yr. B.S. in: (1) Geol., (2) Mng. Eng. (3) Met. G. Letendre, director, Dept. of Mining and Metallurgy.

McGill University, Montreal, P. Q. 4-yr. B. Eng. in: (1) Mng. Eng., (2) Met. Eng. J. J. O'Neill, dean of Engineering.

Ecole Polytechnique (Montreal University), Montreal, P. Q. 5-yr. B. Applied S. in: (1) Mng. Eng. and Geol., (2) Met. Eng. P. Mauffette, head, Dept. of Mining and Geology. L. Bourgoin, head, Dept. of Metallurgy.

Nova Scotia Technical College, Halifax, N. S. 5-yr. B. Eng. in Mng. Eng. A. E. Flynn, professor of mining engineering.

Queen's University, Kingston, Ont. 4-yr. B.S. in: (1) Mng. Eng., (2) Met. Eng., (3) Economic Geol. A. V. Corlett, head, Dept. of Mining Engineering; T. V. Lord, head, Dept. of Metallurgical Engineering; E. L. Bruce, head, Dept. of Geology.

University of Toronto, Toronto, Ont. 4-yr. B. Applied S.: (1) Mng. Eng., (2) Met. Eng., (3) Mng. Geol. R. E. Barrett, professor of mining engineering; L. M. Pidgeon, professor of metallurgical engineering; E. S. Moore, head, Dept. of Geological Sciences.

Board Acts on Publications at June Meeting

Meeting on June 15, the AIME Board of Directors, with President Young presiding, accepted with much satisfaction the report of the tellers in the recent dues referendum, as published in the July journals. Amendment of the Bylaws effecting the increase will be voted at a Board meeting on July 27. Also, the report of the Nominating Committee, nominating Donald H. McLaughlin as President in 1950, was accepted. The names of the nominees were published last month. The Board named Gail F. Moulton as the ninth candidate for Director, inasmuch as otherwise the Petroleum Branch would have no representative in the New York metropolitan area. Candidates for Divisional offices, as printed in the July journals, were announced except that R. W. French is named as a Vice-Chairman of the Petroleum Division instead of a member of the Executive Committee.

Prices were set, on the basis of orders so far received and expected future sales, for the three volumes of Transactions to be issued early in 1950, consisting of the material in the Transactions sections (Section 3) of the journals in 1949. An opportunity was provided on the 1949 dues bill and selection slip for ordering these volumes, and further copies will be available as long as the supply lasts. The price will be $3.50 to members including Student Associates for a first copy of any or all of the three volumes; additional copies will be billed at the nonmember price of $7 each. These volumes will be known as "Transactions, AIME, 1949," thus duplicating in date the volumes authorized for publication this year, but the volume numbers will be different and it is thought that in future it will be desirable to have the volumes carry the date of publication in the journal.

The three journals will be available next year on the same basis as in 1949: one free subscription to one journal as part consideration of dues, with one subscription to either or both of the other journals at $4 each. Additional subscriptions to one journal will be billed at the nonmember subscription price of $8 per year, or $9 to foreign countries outside of the Americas.

Authorization was voted to follow the recommendation of the Seeley W. Mudd Memorial Fund Committee to send to all new Junior Members who have not received any of the Mudd books, and to future new Junior Members, one copy each of "Seventy-five Years of Progress in the Mineral Industry" (75th AIME Anniversary volume), and "A Professional Guide for Junior Engineers," by William E. Wickenden, recently published by the Engineers Council for Professional Development. Also, any one of the following volumes will be supplied free on request: "Modern Uses of Nonferrous Metals," "75 Years of Progress in Iron and Steel," "A Brief History of the Science of Metals," and "Coal Through the Ages."

Other recommendations of the Mudd Committee accepted included: (1) Building up the "AIME Series" to twelve or fifteen volumes, including one of specific interest to each of the professional Divisions of the Institute. (2) Promoting the sale of the volumes through increased publicity. (3) Printing of 3000 copies of the revised edition of "Coal Preparation," to be sold to members and Student Associates at $4 for a first copy, $8 to nonmembers and for additional copies to members, and $6 in lots of ten or more. (4) R. Dawson Hall to be editor of the previously authorized volume on health and safety in mining.

At the Annual Meeting in San Francisco, the resignation of the H. W. Johnson Committee, appointed more than a year earlier and whose report had been made at the Annual Meeting in 1948, was received. The Board had been loath to accept it, and the matter had been discussed at successive Board meetings this spring. The Committee had been especially invited to appear before the Board at its June meeting to discuss the progress so far made in adopting the Committee's recommendations. Mr. Johnson and Messrs. Leighton and Ball, however, felt that the resignation should stand, so it was accepted, with full appreciation of the excellent report that the Committee had made, on which the recent and present reorganization of the Institute structure, practice, publication policies, and personnel has been based.

In the effort to reduce costs of Institute operation, and to improve its service, Mr. Head gave a progress report on plans to survey the office procedure of the AIME and the other Founder Societies; Mr. Beall gave data on possible savings that might result from splitting the personals into Section 1 of the appropriate journals; and Mr. Appleton reported on an investigation of the possibility of reducing printing costs. It was voted to continue publication of the personals in the All-Institute section for the rest of 1949.

Selection of Francis H. Brownell as Rand Medalist for 1950 was approved. Gail F. Moulton was appointed to serve out Mr. Roosevelt's term as representative on United Engineering Trustees. AIME representatives at the First Pan-American Engineering Congress in Rio de Janeiro, July 15-24, were named as follows: Fred T. Agthe, W. H. Carson, John H. Evans, Sherwin F. Kelly, and Henrique Capper Alves de Souza. Additional representatives at the Empire Mining and Metallurgical Congress in Great Britain, July 9-23, were named as follows: P. J. Cutting and W. E. Wrather. William J. Coulter and Lloyd E. Elkins were named as representatives at the 75th anniversary celebration of the Colorado School of Mines, Sept. 29 to Oct. 1. New Affiliated Student Societies were recognized at the University of Pennsylvania—the Metallurgical Engineering Society, and at Penn State—the Petroleum Engineering Society. Progress was reported in organizing the Mining, Geology, and Geophysics Division of the AIME, with the assistance of E. R. Borcherdt.

Directors present included: Messrs. Young, Bowles, Daveler, Head, Kinzel, Kraft, Millikan, Pehrson, Rhines, Schumacher, Sullivan, Suman, Swainson, Swift, Wrather, and Fletcher, with H. P. Greenwald as alternate for N. G. Alford. The meeting, which adjourned at 4:10 p.m., was preceded by an informal luncheon at 12:30.

Mid-Year Meeting . . .

Committeemen for the Mid-Year Meeting pose, with Scott, Faust, Mueller, Johnson, Nekervis, and MacQuigg in the front row, and Westerman, Anderson, Bowers, Pfoor, Melvin, Snavely, and Deubner backing them up.

They wouldn't fit in one picture, so seated are: O'Rourke, Bowen, Reilly, Jones, Spretnak, Salsich; and standing: Hatch, Greenidge, MacIntosh, Cunningham, Woodward, Pilcher, Reed, Alkire, and Advent.

More Important Sessions

Reports are still coming in from Division Chairmen and committee heads regarding plans for the Mid-Year Meeting to be held in Columbus, Ohio, from September 25-28. A detailed program will be printed in the September issues of the Institute Journals.

industrial pollution session

Recognizing the increasing importance of air pollution problems, especially as related to the mineral industries, the Coal Division's Program Committee has scheduled an afternoon of discussion of the topic for Wednesday, Sept. 28. Elmer Kaiser, Committee Chairman, has announced that four nationally known authorities will address the symposium.

L. C. McCabe, formerly with Los Angeles County, and now with the Bureau of Mines in Washington, will discuss "Air Pollution by Industrial Gases and Liquids," and T. C. Wurts will present a paper on the "Air Polluting Solids of Allegheny County, Pa." Allegheny Co., in May, adopted new air pollution regulations, evolved by industry itself, to help cope with the local problem. Discussion will be conducted by H. F. Hebley, of the Pittsburgh Consolidated Coal Co., well-known as a pioneer in anti-pollution work, and W. C. L. Hemeon, noted authority with the Industrial Hygiene Foundation.

Members are urged to attend this very timely and important session.

The Women's Committee affairs are handled by Mesdames MacIntosh, Kaiser, Burnhagen, Anderson; back row, Mesdames Mueller, Elsea, Pilcher, Scott, and Manning.

students urged to attend forum

Another lively student forum will be held during the Mid-Year Meeting. Armed with experience gleaned from forums at El Paso and San Francisco, the young men will face prospective employers in what promises to be a highly informative session.

Industrial leaders are prepared to answer a lot of questions from this year's crop of graduates and students, especially in view of the dearth of jobs available these days. C. E. Bales, vice-president of the Ironton Fire Brick Co.; M. D. Cooper, vocational training manager, National Coal Assn.; and James Hyslop, executive vice-president, Hanna Coal Co., will be among those attending. Person-to-person contact with employers, plus a closeup view of AIME activities, will prove valuable to students. A special student rate for attending the meeting is expected.

Students are urged to seek out plane, train, bus, and hitch-hiking schedules before September. *Professors will please contact their students now, and urge their attendance.*

. . . Columbus, Ohio, September 25 to 28

The Drift of Things

. . . as followed by EDWARD H. ROBIE

More Government Control Threatened

Many officials of companies engaged in the extraction of our country's mineral wealth are alarmed at the implications of an extension of authority assumed by the Federal Power Commission toward the producing, gathering, and marketing functions of the natural gas industry. For years the majority opinion of the Commission has been that it had no powers under the Natural Gas Act of 1938 to regulate production, but one of the five Commissioners has recently altered his point of view. To clarify the Commission's authority, and to maintain the attitude heretofore taken, bills known as the Lyle and Harris bills have been introduced into the House, and more recently Bill No. 1498 has been introduced into the Senate by Senator Kerr, of Oklahoma, on behalf of himself and Senator Thomas, also of Oklahoma.

If peacetime natural gas production and its sales can be controlled by the Federal Power Commission, then it is argued that all mineral resources could likewise be controlled, which is the occasion of the present alarm by some of the mining group.

We have asked one more conversant with the situation than are we to prepare a statement which we are glad to quote as follows:

"Americans who believe that private development of our mineral resources will continue to produce the greatest benefits for the country should be interested in legislation introduced in the 81st Congress. The proposed law, known as the "Kerr Natural Gas Bill," would amend the Natural Gas Act of 1938 by more clearly defining the powers of the Federal Power Commission over the production and gathering of natural gas.

"Briefly, the National Gas Act of 1938 gave the Federal Power Commission power to regulate *interstate* transportation of natural gas and its sale in *interstate* commerce for resale. The Act did *not* grant power to regulate production or gathering. In turn this was long believed to exclude power to regulate the prices charged by producers and gatherers.

"In recent years, however, the jurisdiction of the Commission has gradually been extended, until now a majority of the Commission's members assert that it should have full control over the prices charged by producers and gatherers of natural gas.

"What does this mean? In operations over which it has jurisdiction, the Commission never allows, under court-approved principles, a return greater than 6½ per cent of the original cost of the properties involved. This rule, if applied to an oil field which produces both oil and gas—and that includes most oil fields in this country—could prevent any return at all from the production of casinghead gas, if the producer has already received the allowed return from his oil production. Furthermore, in the case of a purely gas-producing field, returns from the sale of gas might be zero if the producer had already recovered the original cost of his property. Also, since the base figure on which a fixed return is allowed is the original cost of a property, no allowance is made for the enhanced value of properties due to new discoveries.

"Under such circumstances it is obvious that the inducements for a property owner to invest in facilities for the production and gathering of natural gas are seriously impaired.

"The Kerr Natural Gas Bill, realizing that Federal regulation of the prices at which natural gas may be sold in the field by producers and gatherers would inhibit the development of this natural resource, and therefore is against the public interest, specifically prohibits such price regulation. Because of the diversity of opinion as to the powers granted by the 1938 Act, such clarification seems desirable.

"The Federal Power Commission has also claimed for itself the power to control the uses to which natural gas shall be put, and to prohibit the sale of natural gas in competition with other fuels in certain areas. It would seem, however, that the end use of any product should be governed by prices, utility, and the desires of the purchaser, and not by government edict.

"Except in time of war, it is not the function of government to control the end use of natural gas any more than it is its function to control the use of lumber, corn, or cotton; coal, lead, or iron. Certainly control over the end use of one commodity could lead to control over the end use of others.

"Eventually, unless restricted by the Kerr Natural Gas Bill or similar legislation, the Federal Power Commission could extend its jurisdiction so as to drive private enterprise out of the natural gas business. Once that is accomplished, it would be a short step to Government control of oil, coal, copper, and other natural resources—with Federal ownership or state socialism as an ultimate result.

"The bill now pending would merely amend the Natural Gas Act of 1938 to limit the Federal Power Commission to the powers originally thought to be conferred upon it.

"It is entirely appropriate for members of the AIME to advise their Senators and Representatives about their views and wishes on this subject."

Jobs Wanted

Our available space is again confined to one page this month, but we do want to get in a word about the plight of the June engineering graduates. Over 1200 of them have registered with the Engineering Societies Personnel Service for jobs as this is written. Of these, 105 are chemicals, 100 civils, 345 electricals, 625 mechanicals, 55 mining and metallurgical, and 40 geology and physics. The Service has approached many large potential employers but is receiving only two or three requests a week for men.

If an employer who reads this can possibly place one of these budding engineers, even if a less well-trained man must be displaced in the process, the investment should prove a good one. Give a man a job, train him, and have him ready when you need him.

File of Key Engineering Personnel Object of EJC Questionnaire

To provide source material for a who's who in engineering research, development, and other scientific operations for use by the National Military Establishment, the Engineers Joint Council acting through The American Society of Mechanical Engineers has accepted the task of providing the Office of Naval Research with the names, addresses, ages, and details of professional and scientific qualifications of 100,000 key engineers in all branches of American engineering.

The source file of key engineering personnel thus obtained will provide a valuable tool for solving a variety of technical personnel problems. Its use will diminish disturbances of the national economy, organization of industry, and the personal welfare of engineers, and provide a means by which national resources of technical personnel can be ascertained. The file will also point up weak spots which should be strengthened by education, training, and other means. As a national asset the body of facts will be available to private industrial, educational, and professional-society planning groups, and for other legitimate purposes.

A four-page questionnaire has been mailed to 100,000 engineers holding the grade of member or higher in eighteeen national professional engineering societies. The returns will be collected by the ASME and turned over to the Office of Naval Research of the National Military Establishment for classification.

The project is the result of a conference held in Washington, D. C., last fall attended by EJC representatives and many other engineering agencies, at which was discussed the need for a list of 25,000 key engineers working in research, development, and other scientific projects who could be called in on a full or part-time basis to work on the broad scientific programs of the National Military Establishment. The task of collecting personal and professional data fell to the EJC as the largest joint agency of the engineering profession. ASME assumed administration of the project as contracting agent of the EJC.

The Engineers Joint Council points out that this is not just another questionnaire, but one sent to engineers selected from the upper echelon of the profession. The data sought is not intended for general government use but will go directly to the engineering agencies of the National Military Establishment, who will make direct use of it. As the questionnaire will provide the key to opportunity to professional and patriotic service, engineers selected to receive it are urged to give it serious attention and to answer all questions fully.

Calendar of Coming Meetings

AUGUST

4 Reno Branch, Nevada Section, AIME.
10 El Paso Metals Section, AIME.
16 Gulf Coast Section, AIME.
22 Alaska Section, AIME.

SEPTEMBER

25-28 American Mining Congress, Metal Mining Convention, Hotel Davenport, Spokane, Wash.
25-28 Mid-year Meeting, AIME, Neil House, Columbus, Ohio.
29-30 ASME, fall meeting, Erie, Pa.
29-Oct. 1 Colorado School of Mines, 75th anniversary celebration.
Sept. 30-Oct. 1 Southern Ohio Section of Open Hearth Committee, AIME, fall meeting, Deshler-Wallick Hotel, Columbus.

OCTOBER

3-4 National Assoc. of Corrosion Engineers, Adolphus Hotel, Dallas.
5-7 Petroleum Branch, AIME, fall meeting, Plaza Hotel, San Antonio, Texas.
13-14 Texas Mid-Continent Oil and Gas Association, annual meeting, Rice Hotel, Houston.
14 Eastern Section, Open Hearth Committee, Iron and Steel Division, annual all-day fall meeting, Warwick Hotel, Philadelphia.
14 Southwestern Section, Open Hearth Committee, Iron and Steel Division, Kansas City, Mo.
17-19 Institute of Metals Division, AIME, fall meeting, Allerton Hotel, Cleveland.
17-21 National Metal Congress and National Metal Exposition, Public Auditorium, Cleveland, Ohio.
17-21 American Society for Metals, annual meeting, Cleveland, Ohio.
17-21 American Welding Society, annual meeting, Cleveland, Ohio.
17-23 AIEE, 1949 Mid-West meeting, Netherland Plaza, Cincinnati.
19-20 Society for Non-Destructive Testing, Cleveland, Ohio.
20-21 Petroleum Branch, AIME, Elks Club, Los Angeles.
24-28 Thirty-seventh National Safety Congress and Exposition, Chicago.
26-27 Joint Fuels Conference, ASME-AIME, French Lick Springs Hotel, French Lick, Ind.
28 Pittsburgh Section of Open Hearth Committee and Pittsburgh Section, AIME, annual fall meeting, William Penn Hotel, Pittsburgh.
28-29 ECPD, annual meeting, Edgewater Beach Hotel, Chicago.

NOVEMBER

1-5 Pacific Chemical Exposition, California Section, American Chemical Society, San Francisco Civic Auditorium.
2-4 American Society of Civil Engineers, fall meeting, Washington, D. C.
7-10 AIChE, annual meeting, Pittsburgh, Pa.
7-12 International congress on tunnel driving in rock formation, organized by the Societe de l'Industrie Minerale. Information on meeting available from French Mining Mission, 1322 18th St., N. W., Washington, D. C.
9-11 Industrial Minerals Division, AIME, Tampa, Fla.
10-14 ASTM, first Pacific area national meeting, San Francisco, Calif.
12-14 Geological Society of America, annual meeting, Hotel Cortez, El Paso.
16-18 Industrial Hygiene Foundation, 14th annual meeting, Mellon Institute, Pittsburgh.

DECEMBER

7 American Mining Congress, Annual Business Meeting, New York City.
8-10 Seventh Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.

JANUARY 1950

18-20 American Society of Civil Engineers, annual meeting, New York.
30 AIEE, winter meeting, New York.

Do Not Send Cash to the AIME

Occasionally members send small amount of cash to the Institute in payment for publications, and sometimes even pay their dues with five and ten dollar bills. Ordinarily such sums arrive safely, and are properly credited, but occasionally such remittances are never received. The Institute wishes again to emphasize that it cannot be responsible in such instances, and urges members to use checks or money orders even for small amounts.

Approaching Prospects for Membership

Among the duties and privileges of all AIME members interested in building up their professional society is the securing of new members. If every member would hold himself responsible for securing just one new member, the growth and prosperity of the AIME would show a startling upturn. Application blanks will gladly be forwarded on receipt of a postal card request. Many blanks are now outstanding, and it should be made clear, in approaching prospects, that the dues for the next three years will be $5 higher for Members and Associate Members, and $2 higher for Junior Members, than is stated on the application blanks.

News of AIME Members

Lew Adamec is at present section superintendent of Cie. Aramayo de Mines en Bolivie, Casilla 674, La Paz, Bolivia. He previously held the post of level foreman for the Braden Copper Co. at Rancagua, Chile.

D. L. Anderson is now addressed at Empresa Minera de Nicaragua, Apartado 195, Managua, Nicaragua.

George Ross Bancroft, Canadian consulting mining engineer, has now changed his address from Vancouver, B. C., to Okanagan Mission, B. C., which will be his future home and address.

Ralph C. Beerbower and **Ralph C. Beerbower, Jr.,** father and son, appeared in the July News all mixed up; the fault was ours. Mr. Beerbower, Sr., is district manager of the Goodman Mfg. Co. Mr. Beerbower, Jr., after graduating from Penn State in 1948, joined the H. C. Frick Coke Co. and was recently assigned to the post of assistant to the superintendent at Leisenring No. 3 Mine, West Leisenring, Pa. We apologize to both gentlemen.

Arthur H. Bunker

Arthur H. Bunker resigned as a general partner of Lehman Brothers on June 30 to become president of the Climax Molybdenum Co. At present a director of the American Metal Co., the Firth Steel and Carbide Corp., and Climax Molybdenum, Mr. Bunker was the founder in 1923 and first president of the U. S. Vanadium Corp. During the recent war he served with the OPM and WPB, becoming chief of staff of the latter.

T. W. Lippert

T. W. Lippert has been appointed manager of publications by the AIME. In this capacity he will also act as editor of the *Journal of Metals*. Mr. Lippert is a graduate of Carnegie Institute of Technology, with a B.S. and M.S. in physics, and for the past sixteen years has been associated with *Iron Age*, serving in latter years as directing editor of that publication, and as a director of the parent Chilton Co.

J. W. Bostick plans to remain at 6028 Folsom Drive, La Jolla, Calif., until next November. His office is still at 3116 Main St., Dallas, Texas, where mail or calls are promptly forwarded by his secretary. Being a University of California man, he has met many old friends and college mates there, in Los Angeles, and in San Francisco.

Arthur E. Buller, who was formerly resident geologist for the Kelowna Exploration Co. at the Nickel Plate Mine, Hedley, B. C., has accepted the post of chief geologist for the Pend Oreille Mines and Metals Co. at Metaline Falls, Wash.

R. W. Crosby is on the staff of the Benguet Consolidated Mining Co., Baguio, P. I. He was previously employed by Marsman and Co. in Manila.

Douglas MacDonald Dunbar, who had been in Chuquicamata with the Chile Exploration Co., has been made assistant to the executive vice-president of that Company. He is now at Company headquarters located at 25 Broadway, New York City 4.

Howells Frechette has been elected vice-president of the American Ceramic Society. Former chief of the industrial minerals division of the Bureau of Mines, Ottawa, he is the first Canadian to hold this post.

Cy W. Greenhalgh, who was research metallurgist for the Remington Arms Co., Bridgeport, Conn., has recently joined the staff of the Old Town Co., in Old Town, Maine, as general manager. He resides at 144 College Rd., Orono.

Jean McCallum retired on May 1 from his service with the National Lead Co., completing a period of almost exactly 31 years. He became connected with National as assistant superintendent of the River Smelting and Refining Co.,

Jean McCallum

Florence, Colo., in 1918, where he handled all phases of the operation and assisted in perfecting the metallurgy at many points. When this plant ceased operations, he was transferred to Collinsville, Ill., as superintendent of the lead smelter of the St. Louis Smelting and Refining Co., from which point he moved to St. Louis as research and development metallurgist for the National Lead branch and Titanium Division. Following five years as plant superintendent of the whitelead and oxide plant, he was made vice-president of the St. Louis Smelting and Refining Co. and manager of the St. Louis Smelting and Refining Works, division of National Lead, which post he held until his retirement. In 1947 he was also made general manager of the Texas Mining and Smelting Division at Laredo, Texas.

Curtis L. Wilson, dean of the School of Mines and Metallurgy, University of Missouri, watches Andrew Fletcher receive an honorary degree of Doctor of Engineering from F. A. Middlebush, president of the University, at the commencement exercises in Rolla, at which Dr. Fletcher delivered the address.

Paul W. Fairchild received an M.S. degree in geology from the University of Kansas in February and is now employed as a junior geologist with the Shell Oil Co. exploration department in a one-year training program.

E. W. Hunt has been appointed superintendent of mines with the Hudson Bay Mining and Smelting Co., Flin Flon, Man.

E. J. Carlyle

E. J. Carlyle officially retires as executive director and secretary-treasurer of the Canadian Institute of Mining and Metallurgy on Sept. 30. He was born in Woodstock, Ont., in 1877 and graduated in mining engineering in 1904 from McGill University. Upon graduation, he received early professional training at Anaconda, Mont., and Arizona. He held various important posts in several foreign countries, as well as Canada, such as for the Sissert Corp. in Russia for whom he designed a smelter and refinery at Salt Lake City. Before his appointment as secretary-treasurer of the Canadian Institute in 1931, he was superintendent of the American Smelting and Refining Co. in Peru. He was made executive director and secretary-treasurer in January 1947.

L. H. Lange, vice-president and consulting metallurgist of the Galigher Co., Salt Lake City, sailed with his wife from New York City on June 15 on the "Robin Hood" for Southwest Africa where he plans to spend several months at Tsumeb. After leaving Tsumeb, time will be spent visiting Johannesburg and the copper properties in Northern Rhodesia before returning to the States.

Geoffrey B. Leech, who had been attending Princeton University, is now working for the Geological Survey of Canada, Ottawa, Ont.

William F. Machonis is employed as a service engineer by Combustion Engineering Superheater Inc., Philadelphia, Pa.

Willam B. MacPhee, formerly of the Minerals Engineering Co. of Los Angeles, is at present with the Castrovirreyna Metal Mines Co., Casilla 101, Santa Ines, Huancavelica, Peru.

Howard Maidment, who had been a student at the University of British Columbia, can be reached at the Polaris-Taku Mining Co., Tulsequah, B. C.

Frederic H. Main, upon leaving Columbia University where he was a lecturer in economic geology during the absence of **C. H. Behre, Jr.,** is now on the staff of the Bertha minerals division of the New Jersey Zinc Co. at Austinville, Va.

W. B. Mather, chairman of the division of mineral technology of the Southwest Research Institute, San Antonio, Texas, before June 1 was with the Midwest Research Institute in Kansas City, Mo.

Richard D. Mayne, manager of the Hannibal, Mo., plant of the Universal Atlas Cement Co., a U. S. Steel subsidiary, became manager of the company's plant at Hudson, N. Y., on June 1. A 1930 graduate of Carnegie Institute of Technology, he joined Universal Atlas in Chicago in 1937 as an industrial engineer. After serving the cement company in various capacities he was appointed assistant plant manager at Hannibal in 1943 and three years later became plant manager.

John B. McIntyre, formerly a student at Oregon State College, is at present working for the U. S. National Museum, Room 331, Washington 25, D. C.

John F. Meissner is president of John F. Meissner Engineers, Inc., 308 West Washington St., Chicago 6. He had been associated with Robins Conveyors, Inc., also of Chicago.

William C. Miller, who was a student at the University of California at Berkeley, is at present working as an assistant mining engineer for the Anaconda Copper Co. He can be reached at 615 W. Park, Butte, Mont.

Robert W. Michael, specialist in the design of diamond recovery equipment, is now engaged with the New York Engineering Co. as consulting engineer in the fabrication of the first mechanical diamond washing unit to be installed in the new Venezuelan alluvial fields. The plant will contain many unique mechanical features, and is to be constructed so that it can be demounted for air transport. The flow sheet will include the latest developments in diamond recovery practice. Mr. Michael may be reached in care of the New York Engineering Co., 75 West St., New York 6.

Frank R. Milliken, assistant manager, Titanium Division, of the National Lead Co., can now be reached at 111 Broadway, New York City, having transferred from Tahawus, N. Y.

B. E. Mix has retired as plant engineer of the Utah Copper Co. at Garfield, Utah, and is now residing at 2767 Claybourne Circle, Salt Lake City.

E. S. Moore, head of the department of geological sciences, University of Toronto, and formerly dean of the school of mines, Pennsylvania State College, retired on June 30 with the title Professor Emeritus after 27 years on the staff.

Jack E. Morris, research engineer of the general technical department of Jones & Laughlin Steel Corp., although still in the same department, can now be reached care of the Company, Jones & Laughlin Bldg., 3rd and Ross St., Pittsburgh 20. He had previously been at Star Lake, N. Y.

R. G. K. Morrison is returning to Canada, and on Sept. 1 will take over the duties of professor of mining engineering at McGill University. Mr. Morrison was a director of the Mysore Gold Mining Co., Ltd., and a managing director of John Taylor & Sons (India), Ltd. The latter company, being an off-shoot of the old London firm of John Taylor & Sons, was formed to take over interests in India, including the management of the four operating companies of the Kolar gold field.

Eric A. Rudd, having resigned from the position of chief geologist of the Broken Hill Pty. Co., of Melbourne, Australia, has taken the chair of mining and economic geology at the University of Adelaide. This is the first university department of mining and economic geology in Australia; Professor Rudd hopes that it will become the center for teaching mining geology on that continent from now on. He can be addressed at the University, North Terrace, Adelaide.

William F. Jahn

William F. Jahn recently returned to the United States from Argentina after eight years consulting work in that country and is now enjoying a vacation on his ranch at Stark, Missoula County, Mont.

Frank E. Siegfreid graduated from the Colorado School of Mines in May and is now employed by Telluride Mines Inc., Telluride, Colo.

Robert C. Stanley, chairman and president of the International Nickel Co. of Canada, delivered the address at the spring convocation held on May 21 at Queen's University, Kingston, Ont. He was the recipient of the honorary degree of LL.D. along with **W. B. Timm,** who retired recently as director of mines, forests and scientific services branch, Department of Mines and Resources; and **Stanley N. Graham,** former head of the department of mining at Queen's.

Waters, Kudlich, Otto, James, Reinhardt, backed by Romischer, Oehler, Jenkins, Boyd, McGleerey, Reed, Petzold, and Thomas pose at the Marvine colliery of the Hudson Coal Co., Scranton, Pa., when James Boyd, director of the Bureau of Mines, made his first visit to the anthracite northern coal field. He was taken on a tour by officials of the Glen Alden Coal Co., Lehigh Coal Co., and the Hudson Coal Co. At the evening banquet in Scranton, Dr. Boyd gave a talk on general economics of the metals and minerals of this country.

Blakemore E. Thomas, of the California Institute of Technology, has been appointed assistant professor of geology at the University of Kansas, Lawrence. Dr. Thomas will teach work in petrography and economic geology.

H. W. Thoms, geologist with the Creole Petroleum Corp., Caracas, Venezuela, will be on vacation in the States from July 1 to Aug. 19. His address while here will be 242 Pacific St., Bakersfield, Calif.

Robert E. Tally, Jr., can be reached care of Eastern Mining and Metals Co., Kuala Dungun, Trengganu, Malaya. He had been with Foley Bros., Inc., at Pasadena, Calif.

Robert Van Nostrand has earned his degree of Master of Science in physics at the Missouri School of Mines and is now working for his doctorate in geology at the University of North Carolina.

C. E. Visel, formerly with the Cia. Minera Nacional at Chihuahua, is now on the staff of Negociacion Minera, Sta. Maria de la Paz y Anexas, Matehuala, S.L.P., Mexico.

Dooley P. Wheeler, Jr., geologist, is now with the American Metal Co.; his address is 232 Judge Bldg., Salt Lake City.

Robert A. Willoughby joined the staff of the Yucca Mining and Milling Co., Box 67, Yucca, Ariz. He had been with the Union Sugar Co. at Betteravia, Calif.

William Wraith, Jr., recently changed his job from the Cananea Consolidated Copper Co. in Sonora, Mexico, to the Chile Exploration Co. in Chuquicamata, Chile.

James H. Wren, after covering a number of Central and South American mining examinations, is back in the United States. He has taken the operational consulting account of the Sunshine Gold Mining Company's Redding, Calif., properties, which are about to be put under production. His address is 4317 D St., Sacramento, Calif.

Charles E. Wyndham is now employed as a mining engineer by the Bureau of Mines and can be addressed care of the Bureau, Box L, University, Ala. He previously worked for the Standard Lime and Stone Co., Kimballton, Va.

Harry J. Wolf

Harry J. Wolf, of Behre, Dolbear and Co., was in Mexico recently inspecting mineral deposits in the state of Chihuahua.

• In the Metals Divisions

Glenn L. Allen, previously associated with L. W. Kelley of Park Ridge, Ill., is now employed by the Reynolds Metals Co., 3rd and Grace Sts., Richmond, Va.

Jay W. Fredrickson

Jay W. Fredrickson, formerly at the University of Utah, has joined the staff of the School of Mineral Industries, Pennsylvania State College, as chief of the division of metallurgy.

Samuel E. Atkins, president of the S. E. Atkins Co., has announced the incorporation of Atkins-Walker Co. Offices will continue at 612 Alworth Bldg., Duluth, Minn. Drilling operations which have been carried on for 29 years by S. E. Atkins Co. were turned over to the new company on May 2.

Francis O. Case, former assistant to the vice-president of the Anaconda Copper Mining Co., has been made a vice-president of the Company.

Raf De Bie has finished his studies at Carnegie Tech and received a master's degree. He is touring the country to see something of our industries and will return to Belgium early in August to start working in the research department of the Trefileries Leon Bekaert at Zwevegem.

Robert D. Fitzgerald has taken the job of assistant metallographer with the Aluminum Co. of America at New Kensington, Pa. His home address in New Kensington is 309 Charles Ave.

Arnold W. Greenius is now attached to the department of research and development of the Dominion Steel and Coal Corp. of Sydney, N. S.

Max Hansen has left his associate professorship at the Illinois Institute of Technology to take a position with the Armour Research Foundation which is located on the IIT campus. Members of the AIME Student Chapter at the school presented Dr. Hansen, who was one of the students' favorite instructors, with a going-away present. The professor had come to the U. S. A. but two years ago, and his departure from the IIT faculty is considered as "great loss to both the department and the students."

John C. Kinnear on June 6 delivered the commencement address to 227 graduates of the University of Nevada. Mr. Kinnear, vice-president of the Kennecott Copper Corp. of New York City, was the recipient of an honorary degree of doctor of laws. In addition to his mining activities, he is vice-president of the Nevada Northern Railway and of the Ely National Bank. **Jay A. Carpenter,** director of the Mackay School of Mines of the University of Nevada, was awarded the honorary degree of doctor of science.

Fritz V. Lenel has been made associate professor in the department of metallurgical engineering at Rensselaer Polytechnic Institute. He earned his doctorate at the University of Heidelberg in 1931, and did graduate work at the University of Goettingen until 1933. He joined the Rensselaer staff in 1946 after ten years with the Moraine products division of General Motors.

John W. Axelson

John W. Axelson recently received a Ph.D. degree from the University of Minnesota where he majored in chemical engineering and minored in metallography. He is now employed as a research engineer doing research and development work on metallic gaskets in the research center of the Johns-Manville Corp., Manville, N. J.

Robert F. Mehl, director of the metals research laboratory and head of the metallurgical engineering department at Carnegie Institute of Technology, Pittsburgh, flew to Brazil on June 29 to be a guest for about four weeks of the Research Institute of the State of Sao Paulo at their fiftieth anniversary. Dr. Mehl will also take part in the dedication of new laboratories at the Cidade Universitaria, and will attend the fifth anniversary of the Brazilian Society of Metals, which he helped organize. He lectured in Brazil in 1943 at the request of Nelson A. Rockefeller, co-ordinator of Inter-American Affairs. Dr. Mehl is a permanent member of the faculty of the University of Sao Paulo, from which he received an honorary doctor's degree.

Norman L. Mochel, manager of metallurgical engineering for the Westinghouse Electric Corp., has been elected a member of the board of the American Society for Testing Materials for a three-year term. First employed in the inspection department of the then Westinghouse Machine Co., he later was responsible for the work of testing materials. During the first World War he served overseas in the Corps of Engineers. For many years he has been in his present position, an authority on the materials going into the turbine and other forms of power generation.

George F. Newton is a trainee with the Steel Co. of Canada, Hamilton, Ont. His mail goes to 1077½ Beach Blvd., Hamilton.

Antonio C. Oliveira is now assistant engineer of the foundry department of Laminacão Nacional de Metais, and his mailing address is Rua Heliotropos, 245 (Vila Mariana), São Paulo, Brazil. He had been associated with the Cia. Siderurgica Nacional at Volta Redonda.

Bruce Pierce was married to Helen Decker on June 18 at a ceremony at the Metropolitan Methodist Church in Washington, D. C. The groom, who is in the ordnance department of the regular army as Lieutenant Colonel, is at present taking a two-year graduate course in engineering at Cornell University. The bride is a native of Washington, D. C., and a graduate of Wilson Teachers College. The couple will reside at R. D. 4, Ithaca, N. Y.

Adolph O. Schaefer, assistant to the executive vice-president of the Midvale Co. of Philadelphia, has been appointed to the research committee of Franklin Institute. A native of Pennsylvania, residing in Broad Ax, Pa., he graduated from the University of Pennsylvania in 1922 with a B.S. in chemical engineering. He joined Midvale as a research assistant shortly after graduation and became engineer of tests in 1937 and executive metallurgical engineer in 1944. He held many important posts during the last war, one of which was that of chairman of the gun development group in the Metallurgical Advisory Board.

Howard Peters

Howard Peters was appointed as project engineer for the rollpin division of the Elastic Stop Nut Corp. of America, Union, N. J. He was previously a vice-president of the Mid-Continent Metal Products Co. of Chicago, and during his employment with that Company developed the process and machinery for producing the rollpin fastener. Mr. Peters is a graduate of Purdue University with a B.S. and M.S. in engineering, and was a member of the staff of Battelle Memorial Institute at Columbus. He served in the U. S. Army during the recent war.

Herbert A. Robinson has the job of research metallurgist at Battelle Memorial Institute, Columbus 1, Ohio. He had been with the American Smelting and Refining Co. at Barber, N. J.

Robert Maddin recently accepted the post of assistant professor of mechanical engineering at Johns Hopkins University. He was formerly a research fellow in metallurgy at Yale.

George B. Waterhouse, emeritus professor of metallurgy at MIT, and consulting metallurgist, was awarded an honorary Doctor of Engineering at the recent Nova Scotia Technical College convocation in Halifax. Dr. Waterhouse delivered the convocation address.

Clyde Williams, director of Battelle Memorial Institute, will give the introductory paper on the conservation of iron and steel in production at the United Nations' Scientific Conference on the Conservation and Utilization of Resources on Aug. 25 at Lake Success, N. Y. **John D. Sullivan,** assistant director of Battelle, is scheduled to present a paper on the new processes for the utilization of low-grade ores five days later. The conference is to be scientific rather than policy-making, according to the UN's Economic and Social Council. It will have no power to bind governments and it will not formulate recommendations to them. The practical application of science to resource management and human use will be the primary concern. During the conference papers will be presented by approximately 450 scientists, engineers, and other experts from many countries.

In recognition of significant contributions in the fields of science and public service, the honorary degree of Doctor of Engineering was recently conferred on Mr. Williams by the Michigan College of Mining and Technology. Prior to the presentation, he delivered the commencement address to over 500 candidates of the Michigan graduating class.

Lincoln T. Work has become associated with Alan R. Lukens at the Powdered Material Research Laboratories, 11 Windsor Street, Cambridge 39, Mass. With the coming of Dr. Work, the organization's field of utility will be widened to undertake work on abrasives, refractories, metal powders, cements, and dusts. He is an authority on grinding, classification, and filtration. Dr. Work had been director of research and development for the Metal and Thermit Corp. for the past nine years. He was on the staff of the chemical engineering department at Columbia University before his affiliation with the Metal and Thermit Corp., and was at that time well known in consulting engineering.

Lincoln T. Work

• In Petroleum Circles

Floyd D. Aaring, former University of Oklahoma student, is a petroleum engineer with the Canadian Gulf Oil Co., P. O. Box B-4, Pincher Creek, Alta.

T. H. Acres is on the staff of the Barnsdall Oil Co., Box 367, Newhall, Calif.

George P. Alden, formerly with the U. S. Geological Survey, has the job of petroleum production engineer with the Barnsdall Oil Co., P. O. Box 2039, Tulsa, Okla.

Arnold D. Arnaut graduated in June from the University of Wisconsin's metallurgy department and is employed by Sylvania Electric Products, 35-22 Linden Place, Flushing, L. I., N. Y.

Leo R. Brammer, Jr., who has been studying at the University of Tulsa, is an engineer with the Dempsey Pump Co., Box 3098, Tulsa, Okla.

E. J. Brook is president of the McElroy Ranch Co. of Fort Worth, Texas. He had been with the Franco Wyoming Oil Co.

Robert E. Brooks is working for the Skelly Oil Co. in the Southern division on production. His address for mail is P. O. Box 224, Wynnewood, Okla.

W. T. Cardwell, Jr., formerly with the Standard Oil Co. of California, is senior research engineer for the California Research Corp., La Habra, Calif.

Campbell M. Carothers, district petroleum engineer for the Humble Oil and Refining Co., is addressed at Rt. 1, Raymondville, Texas.

A. L. Carpenter has the post of junior petroleum engineer in the production department of the Humble Oil and Refining Co., Bay City, Texas.

Aaron Cawley, who has been studying at the University of Texas, is now working as engineering trainee for the Honolulu Oil Corp. He can be addressed at Box 1979, Denver City, Texas.

John H. Chain has a job with the American Republics Corp., Box 547, Artesia, N. Mex. He was a student at the University of Texas.

Thomas E. Covington is an engineer trainee with the Tidewater Associated Oil Co., Box 12, Venice, La.

Joseph E. Barthelemy, Jr., who attended the University of St. Louis, is now employed by the Western Geophysical Co., P. O. Box 103, Lac La Biche, Alta.

Rex M. Everett is working for the Magnolia Petroleum Co. in Kermit, Texas. He had been a student at the University of Oklahoma.

Stewart H. Folk has resigned his post at Baylor University in order to accept an assignment with DeGolyer and MacNaughton, consulting geologists and engineers, as their representative in Mexico. His address is now in care of Petroleos Mexicanos, Depto. Exploracion,

Rm. 208, Avenida Juarez 95, Mexico City, D. F.

Thomas E. Goebel is in Maracaibo, Venezuela, working for the Cole Drilling Co.

Harold C. Kidd, who attended the University of Tulsa, is on the staff of the Creole Petroleum Corp., Apt. 172, (Laqunillas), Maracaibo, Venezuela.

J. B. Ladd received a B.S. degree in petroleum engineering from the University of Kansas in June and is now employed by The Texas Co. in Cut Bank, Mont.

Kenneth H. Larson, a former student at the Montana School of Mines, is now a junior computer of the Stanolind Oil and Gas Co. His mail address is 1145 Monroe, c/o Stanolind Oil and Gas Co., Seis Party 14, Alexandria, La.

Clinton C. Lieffers, formerly on the staff of the Texas Amerada Petroleum Corp., is now working in the geology department of the Creole Petroleum Corp., Apt. 889, Caracas, Venezuela.

William G. Locke is tar products sales cadet in the tar products division of the Koppers Co., Pittsburgh.

Arthur F. Malicoat is a paleontologist with the Gulf Oil Corp. He receives his mail at his home, 1302 S. 49th St., Temple, Texas.

W. J. Mannas writes that his mail should be addressed to the Pure Oil Co., 35 E. Wacker Drive, Chicago.

William J. McPherson has changed his address from Stanford University to care of Imperial Oil Ltd., 300 9th Ave. W., Calgary, Alta.

Ralph J. Poth has taken a job with the Union Sulphur Co., with Box 511, Sulphur, La., for an address.

Dayton E. Ramsey recently joined the staff of Dowell, Incorporated, Kermit, Texas. He is a former student of Texas A&M.

P. H. Rumsey is addressed in care of the Iraq Petroleum Co., Ltd., (Exploration), Tripoli, the Lebanon. He took the job of junior geologist with the company over a year ago.

H. J. Schroeder has gone to Talara, Peru, as petroleum reservoir engineer with the International Petroleum Co. He had been in the Baroid Sales Division of the National Lead Co. at Houston.

Richard G. Stephens, who studied at the University of Texas at Austin, and was formerly employed by The Texas Co. as a trainee, is at present on active duty in the U. S. Navy. His mail will reach him at 3206 King's Rd., Dallas, Texas.

John F. Stickel, Jr., is a geological engineer with the Wesley, Beford and Stickel Co. of Detroit, Mich.

Todd C. Storer has been transferred by the Stanolind Oil and Gas Co. to Bishop, Texas, where he is field engineer in the Luby area.

Marshall C. Turner is production superintendent for the Continental Consolidated Corp., Long Beach, Calif. He had been with the Union Oil Co.

William E. Topley, a Montana School of Mines student, is now geologist for the Stanolind Oil & Gas Co., 336 8th Ave. West, Calgary, Alta.

Necrology

Date Elected	Name	Date of Death
1918	Paul Armitage	June 28, 1949
1936	William A. Bauerıs	Feb. 23, 1949
1936	William Bell	1948
1945	W. A. Bishop	June 10, 1949
1942	T. C. Botterill	June 15, 1949
1947	Tore Flygare	November, 1947
1918	Walter Miller	Unknown
1916	Clarence J. Peterson	May 8, 1948
1904	E. A. Cappelen Smith	June 25, 1949

Proposed for Membership

Total AIME membership on June 30, 1949, was 15,759; in addition 4424 Student Associates were enrolled.

ADMISSIONS COMMITTEE

James L. Head, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, T. B. Counselman, Ivan A. Given, George C. Heikes, Richard D. Mollison, and Philip D. Wilson.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

ALABAMA

Birmingham — AUSTIN, WILLIAM WYATT, JR. (C/S—J-M). Research metallurgist, Southern Research Institute. SANDELIN, ROBERT WILLIAM. (C/S—J-M). Chief metallurgist, Stockham Values & Fittings, Inc.

ARIZONA

Morenci—BACON, FREDERICK MASON. (AM). Flotation operator, Phelps-Dodge Corp.

Phoenix—POPPINO, CARL ALBERT. (AM). Sales engineer, General Electric Co.

ARKANSAS

Magnolia—ALGER, ROBERT PERDUE. (C/S—J-M). District engineer, Schlumberger Well Surveying Corp.

CALIFORNIA

Alhambra — JAMISON, PAUL HUGUS, JR. (C/S—J-M). Sales promotion engineer, Kobe, Inc. STICK, JOHN C., JR. (C/S—J-M). Chief electrical engineer, Lane-Wells Co.

Bakersfield — CARRICK, HARRY HALL, JR. (C/S—J-M). Resident engineer, General Petroleum Corp. MANGOLD, ROBERT P. (C/S—J-M). Petroleum engineer, Independent Exploration Co. PERRY, CLYDE WILBERT. (C/S—J-M). Division petroleum engineer, Richfield Oil Corp. YAMAMOTO, ROY HIDEO. (R,C/S—S-J). Assistant engineer, bottom-hole lab., Core Laboratories, Inc.

Berkeley—PARKER, EARL R. (C/S—J-AM). Associate professor of metallurgy, University of California. WICKETT, WALTON AMES. (R,C/S—S-M). Western sales manager, Tracerlab, Inc.

Huntington Park — ANDERSON, JAMES LOUIS. (M). Chief engineer, Conveyor Co. WISEMAN, KENNETH WILLIAM. (J). Trainee-petroleum engineering, Socony-Vacuum Oil Co.

La Habra — SWENY, JOHN WILLIAM. (C/S—J-M). Associate research engineer, California Research Corp.

Lompoc — GRIMM, KENNETH E. (C/S—J-M). Paleontologist, Johns-Manville Products Corp.

Long Beach — CARRIEL, JAMES TURNER. (C/S—J-M). Petroleum engineer, Southwest Exploration Co. HILTY, GEORGE CLIFFORD. (C/S—J-M). Petroleum engineer, Long Beach Harbor Dept. INSKEEP, WILLIAM DOLMAN. (M). Drilling contractor.

Los Angeles — BEAL, CARLTON. (C/S—J-AM). Consulting petroleum engineer. LESTER, GRAHAM WALLACE. (J). Engineer's assistant, Union Oil Co. of California. MASON, HAMILTON. (C/S—J-M). Service engineer, North American Aviation, Inc.

Orcutt—HILTON, ALFRED GEORGE. (M). Division drilling foreman, Union Oil Co. of California.

Pasadena—OLSEN, HAROLD TORMOD. (C/S—J-M). Petroleum engineer, Superior Oil Co. TAYLOR, JACK LESLIE. (C/S—J-M). Research engineer, jet propulsion lab., California Institute of Technology. TROMBLE, JAMES PREMONT. (C/S—J-M). Engineer inspector, Bureau of Power and Light.

Sacramento — LANG, HENRY ADOLPH. (C/S—J-M). Sales engineer, Ingersoll-Rand Co.

San Francisco — RUHLMAN, FRED LEE. (C/S—J-AM). Commander, U. S. Navy. WOOD, GERRIT V. (AM). Western sales manager, Taylor-Wharton Iron and Steel Co.

San Marino—WOODWARD, ALBERT FLETCHER. (C/S—J-AM). Senior petroleum engineer, Union Oil Co.

Whittier — FRASER, JOHN REID. (C/S—J-M). Division engineer, Union Oil Co. of California. ZINSZER, RICHARD HOWARD. (C/S—J-M). Group leader-research, Union Oil Co.

COLORADO

Climax—HARTMAN, LOUIS WOODSON. (J). Resident geologist, Climax Molybdenum Co. KMINEK, JOHN MILAN. (C/S—S-J). Engineer, Climax Molybdenum Co.

Denver—BARNES, JOHN WALLACE (C/S—J-M). Engineer, mining dept., Stearns-Roger Mfg. Co. MATTSON, TAUNO OTTO HENRY. (C/S—J-M). Division petroleum engineer, The Texas Co.

Gilman—VITZ, HOWARD ENGELER (C/S—J-M). Geologist, New Jersey Zinc Co.

Pueblo — ZADRA, JOHN ROBERT. (C/S—J-M). Assistant chief metallurgist, Colorado Fuel and Iron Corp.

CONNECTICUT

Cheshire — BURRALL, STEPHEN HART. (M). Representative, central technical dept., American Brass Co.

S. Norwalk — MANNING, JOHN PEARCE, JR. (C/S—J-AM). Draftsman designer, Anaconda Copper Mining Co.

Waterbury—KIRBY, PHILIP HULL. (R,C/S—J-M). Metallurgical engineer, American Brass Co.

Watertown — CANDEE, ELLSWORTH T. (C/S-J-AM). Director of research and development, Lea Mfg. Co.

DISTRICT OF COLUMBIA

Washington—LINDBERG, RUSSELL AXEL. (C/S—J-M). Metallurgist, National Bureau of Standards.

FLORIDA

Jacksonville—BROWN, D. GRANT.

(M). Vice-president, Humphreys Gold Corp.

IDAHO

Kellogg — REYNOLDS, JOHN R. (C/S—J-M). Partner, Preston & Reynolds.

Moscow — PRATER, LEWIS SEWARD. (C/S—J-M). Assistant director, Idaho Bureau of Mines and Geology.

Patterson — McFARLANE, JAMES CARL. (C/S—J-M). Chief engineer, Bradley Mining Co.

ILLINOIS

Centralia — CAMERON, CHARLES VINCENT. (C/S—J-M). Division exploitation engineer, Shell Oil Co.

Chicago — HESS, JAMES BROWN. (C/S—J-M). Metallurgist, Institute for Study of Metals, University of Chicago. JUSTER, NATHAN B. (C/S—J-M). Metallurgist, Inland Steel Co. MARTIN, PASCHAL. (C/S—J-M). Chief production engineer, Pure Oil Co. ZENER, CLARENCE. (C/S—J-M). Professor of physics, University of Chicago.

Cicero—KIZIOR, JEROME JOSEPH. (C/S—S-J).

Danville—OBRIG, VICTOR J. (C/S—J-M). Metallurgical engineer, central foundry div., General Motors.

Flora—BROWN, BOB DIGGS. (M). Division engineer, Halliburton Oil Well Cementing Co.

Peoria—LEBER, SAM. (C/S—S-J).

Salem — WRIGHT, FRED S., JR. (C/S—J-M). District petroleum engineer, Magnolia Petroleum Co.

Urbana — SEITZ, FREDERICK. (C/S—J-AM). Research professor, University of Illinois.

Winnetka — BURGOYNE, WILLIAM RICHARD. (C/S—J-M). Production manager, U. S. Gypsum Co.

INDIANA

East Chicago—SQUARCY, CHARLES M. (C/S—J-M). General foreman, Inland Steel Co.

Hammond—DANCHI, GEORGE. (J). Student, Purdue University.

Terre Haute—TOELLE, HARRY A., JR. (C/S—S-J). Junior mine shift boss, Braden Copper Co.

LOUISIANA

Bernice — TAYLOR, CLARENCE PIERCE. (J). Junior petroleum engineer, Hunt Oil Co.

New Orleans — LANGHETEE, EDMOND JOSEPH, JR., (J). Junior engineer, Louisiana Land and Exploration.

Shreveport—MELTZER, LEE HILLIARD. (C/S—J-M). Geologist, Union Producing Co.

MARYLAND

Baltimore — McGAVOCK, CECIL BILLUPS, JR. (C/S—J-M). District geologist, Corps of Engineers, Baltimore District, U. S. Army.

Silver Spring—ST. CLAIR, HILLARY W. (C/S—J-M). Metallurgist-in-charge, Metals Recovery & Refining Section, Bureau of Mines.

MASSACHUSETTS

Attleboro — PETERSON, ARTHUR WILLIAM (C/S—J-M). Metallurgical engineer, assistant professor, MIT.

Cambridge — BAIRD, WALTER SCOTT. (C/S—J-AM). President, Baird Associates, Inc.

Reading — DASHER, JOHN ORNDOFF. (C/S—J-M). Executive officer mineral engineering lab., MIT.

MICHIGAN

Bay City — SIMONS, JEROME. (J).

Bessemer—EASTMAN, EUGENE ALBERT. (C/S—S-J). Student, Michigan College of Mining & Technology.

Coldwater—GRAY, LATHAM BURBERRY, JR. (C/S—S-J).

Detroit—SCHWARTZ, DONALD L. (C/S—J-M). Research metallurgist, Carboloy Co.

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Ironwood — CHRISTENSON, ALFRED JOHN, JR. (C/S—S-J).

Ishpeming — PETERSON, BERNHARDT HERBERT. (J). Production engineer, Cleveland-Cliffs Iron Co.

MINNESOTA

Ely—BERKNER, DONALD A. (C/S—J-M). Mining engineer, Pioneer mine, Oliver Iron Mining Co.

MISSISSIPPI

Jackson—WEBB, SAM NAIL. (C/S—J-M). Assistant division geologist, Honolulu Oil Corp.

MISSOURI

Rolla — FINE, MORRIS MILTON. (C/S—J-M). Senior metallurgist, Metallurgical Branch, Bureau of Mines.

MONTANA

Butte — WAYLETT, WILLIAM JAMES. (C/S—J-M). Assistant mine engineer, Mining Engineering Dept., Anaconda Copper Mining Co.

NEVADA

Pioche—DURK, ROBERT ROY. (M). Assistant superintendent, Combined Metals Reduction Co.

NEW JERSEY

Hackettstown—FEDUSKA, STEPHEN LESTER. (C/S—J-M). Foundry superintendent, Thomas & Skinner Co.

Kearny—SMITH, GEORGE V. (C/S—J-M). Research metallurgist, research lab., U. S. Steel Corp.

Orange—PREUSCH, CHARLES DANIEL. (C/S—J-M). Metallurgist, Crucible Steel Co., of America.

Summit—MARBLE, EARL ROBERT, JR. (C/S—J-M). Metallurgical engineer, American Smelting & Refining Co.

NEW MEXICO

Albuquerque — ITALIA, SANTO (C/S—S-AM). Student, Classified training, USAF.

NEW YORK

Glen Cove — McGAULEY, PATRICK JOHN. (C/S—J-M). Project engineer, Chemical Construction Corp.

Jackson Heights — LANDA, MAYNARD IVAN. (M). Manager, economics and statistics, Petroleum Advisers, Inc.

Kenmore—BRAY, JOSEPH MOYER. (C/S—J-M). Director of mining division, Osmose Wood Preserving Co.

Lewiston — OFFENHAUER, CHARLES MARTIN. (C/S—J-M). Research metallurgist, Union Carbide & Carbon Research Labs.

New York — CHANG, LO CHING. (C/S—J-M). Research metallurgist, Crucible Steel Co. of America. LANGE, ESWORTHY PAUL. (C/S—J-M). Operating manager, Saudi Arabian Government Gypsum Project. ROBERTS, BEN DAVID. (C/S—J-M). Ore buyer, American Smelting & Refining Co. ULRICH, GEORGE H., JR. (AM). District engineer, Link Belt Co.

Ozone Park — SCHNITZEL, RANDOLPH HUFF. (J).

Rye—BIER, CECIL JOSHUA. (C/S—J-M). Chief engineer, Powmetco, Inc.

Saratoga Springs—CLUGSTON, EDGAR JOSEPH. (M). Division head, metallurgical processing division, Saratoga Labs., Inc.

Schenectady—COFFIN, LOUIS FUSSELL, JR. (M). (After Sept., 1949), Research associate, General Electric Co. HARRINGTON, RICHARDS HARRY. (M). Research associate, General Electric Co.

Tahawus—MEAD, JOSEPH CHARLES. (R,C/S—S-M). Sinter plant superintendent, National Lead Co.

Tonawanda — McCANDLESS, EDWARD L. (C/S—J-M). Assistant superintendent, research lab., Linde Air Products Co.

Tuckahoe — MOLLISON, RICHARD D. (C/S—J-M). Mining engineer, Texas Gulf Sulphur Co.

Yonkers—MARTIN, WILLIAM DAY. (C/S—J-M). Production engineer, Tide Water Associated Oil Co.

OHIO

Cincinnati—BARTON, FRANK PRESTON. (C/S—J-M). Cincinnati branch manager, metallic products div., Eagle-Picher Co.

Cleveland — CAREY, ROBERT S. (AM). Iron ore sales, Pickands Mather & Co. HUNSICKER, HAROLD YUNDT. (C/S—J-M). Assistant chief, Cleveland research div., Aluminum Research Labs., Aluminum Co. of America. STEFAN, PETER. (C/S—J-M). Development engineer, Alloy Metal Wire Co.

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Columbus Grove—BASINGER, VIRGIL D. (C/S—S-AM). Metallurgical engineer, Cincinnati Milling Machine Co.

Elyria — HOEL, ALFRED G., JR. (C/S—J-M). Vice-president, Concrete Masonry Corp.

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Newark — CARTER, ANTHONY J., JR. (R,C/S—S-J). Division production engineer, Pure Oil Co.

Portsmouth — LENHART, ROBERT EUGENE. (C/S—S-J). Member, Scientific Training Program, General Electric Co.

Powell — LYONS, ORVILLE RICHARD. (C/S—J-M). Research engineer in charge of coal preparation, Battelle Memorial Institute.

OKLAHOMA

Bartlesville — DEAN, MAURICE R. (M). Senior chemical engineer, Phillips Petroleum Co. PRANGE, FREDERICK A. (C/S—J-M). Metallurgical engineer, Phillips Petroleum Co.

Healdton — STITT, IRA BEY, JR. (C/S—J-AM). District engineer, Magnolia Petroleum Co.

Oklahoma City — WASZOWSKI, HENRY LOUIS, JR. (C/S—J-M). Division petroleum engineer, Magnolia Petroleum Co.

Ponca City — REYNOLDS, JACK J. (C/S—J-M). Supervising research engineer, Continental Oil Co.

Tulsa — BARTON, ROBERT CLINTON. (R,C/S—S-AM). Production engineer, Gulf Oil Corp. CARUTHERS, C. B. (C/S—J-M). Unitization superintendent, Stanolind Oil & Gas Co. CHAPELL, DONALD OWEN. (M). Vice-president, exploration and land dept., Sunray Oil Corp. CONNER, JAMES CLARK. (C/S—J-M). Contract sales engineer, Stanolind Oil & Gas Co. FRANCIS, ALEX WALLACE, JR. (C/S—J-M). Assistant chief engineer, National Tank Co. STEARNS, GLENN M. (C/S—J-M). Development superintendent, Stanolind Oil & Gas Co.

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Portland—HATTAN, ELTON MUMPOWER. (M). Field examiner (mining), Bureau of Land Management, Department of the Interior. MASON, RALPH S. (C/S—J-M). Mining engineer, Oregon Dept. of Geology and Mineral Industries.

PENNSYLVANIA

Bethlehem — EBERHARDT, JOHN ERNST. (C/S—J-M). Engineer, Bethlehem Steel Co.

Cornwall — OLSEN, HAROLD OLIVER. (C/S—J-M). Superintendent, Bethlehem Steel Co.

Edgewood—BANK, WALTER. (C/S—J-M). Chemist-petrographer, Bureau of Mines.

Forty Fort — ARBOGAST, KARL FRANK. (M). General manager, Lehigh Valley Coal Co.

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Johnstown—STOTZ, EDWARD WESLEY, (C/S—S-J). Metallurgist, Bethlehem Steel Co.

Kingston—MORGAN, DANIEL JOHN. (AM). Sales engineer, Hazard Insulated Wire Works. WEICHEL, THOMAS ROBERT. (M). Mining-electrical engineer, Hazard Insulated Wire Works.

Masontown — GIROD, MICHAEL B. (M). Mine superintendent, H. C. Frick Coke Co.

Northampton — ANTHONY, STANLEY EDWARD. (M). Flotation engineer, Separation Process Co.

Philadelphia — JAMIESON, ARCHIBALD LIVINGSTON. (C/S—J-M). Metallurgist, Frankford Arsenal.

Pittsburgh—BRANCH, RAE WELLS. (AM). Manager, Pittsburgh district office, Whitney Chain & Mfg. Co. HAWKES, MALCOLM FRANK. (C/S—J-M). Associate professor of metallurgical engineering, and member of staff, metals research lab., Carnegie Institute of Technology. LIPANOVICH, AUGUST JOHN. (C/S—J-M). Assistant ceramist, Vesuvius Crucible Co. SERGY, WALTER THOMAS. (J). Steel works metallurgist, Pittsburgh works, Jones & Laughlin Steel Corp.

Wilkes-Barre — KOPPELMAN, JACK KEITH. (C/S—S-J). Sales engineer, Goodman Mfg. Co. STOTT, ROY GEORGE. (C/S—J-M). Mining engineer, Bureau of Mines.

Wyoming — WEIR, JOSEPH STANLEY. (M). Civil engineer, Bureau of Mines.

SOUTH DAKOTA

Lead—KELLAR, KENNETH CHAMBERS. (R—AM). Assistant chief counsel, Homestake Mining Co.

TENNESSEE

Columbia — AALL, CHRISTIAN HIORTH. (AM). Research field technologist, Monsanto Chemical Co.

Knoxville—LAURENCE, ROBERT A. (C/S—J-M). Regional geologist, U. S. Geological Survey.

TEXAS

Abilene—JENKE, ARTHUR L. (C/S—J-M). Engineer in charge of lab., Abilene Sample Log Service and Core Labs.

Austin—HALL, JAMES AUGUSTUS, JR. (C/S—J-M). Senior petroleum engineer, R. R. Commission of Texas. LEBEAUX, JACOB M. (J). Assistant professor of petroleum engineering, Univ. of Texas.

Bay City — CARPENTER, ALBERT LEWIS. (C/S—S-AM). Jr. petroleum engineer, Humble Oil & Refining Co.

Corpus Christi — WATERMAN, CHARLES NATHAN. (M). Plant manager, American Smelting & Refining Co.

Dallas — COLDWELL, CHARLES HATTON. (C/S—J-M). Exploitation geologist, Sun Oil Co. DAVIS, LOUIS FREEMAN. (C/S—J-M). Senior mechanical engineer, Atlantic Refining Co. KEATING, J. PATRICK. (C/S—S-J). Petroleum engineer, Magnolia Petroleum Co. MYERS, RICHARD. (C/S—J-M). Petroleum engineer, Magnolia Petroleum Co. PATTON, E. CHARLES, JR. (C/S—J-M). In charge of reservoir engineering, Magnolia Petroleum Co. TAYLOR, EARLE FREDERICK. (C/S—J-M). Geologist, DeGolyer & MacNaughton.

Fort Worth — GEROLDE, STEVEN. (C/S—J-M). District petroleum engineer, Gulf Oil Corp. WILEY, PAUL M. (C/S—J-M). Division reservoir engineer, The Texas Co.

Freer — BARRETT, WARREN JEFFERSON. (M). Assistant district superintendent, Humble Oil & Refining Co.

Ganado — ELLIS, JOHN EDWIN. (J). Field engineer, The Texas Co.

Graham — WILLIBRAND, ALPHONSE FRED. (M). District manager, Schlumberger Well Surveying Corp.

Houston — BLACK, IRA LESTER. (J). Portable laboratory supervisor (Houston area), Shell Oil Co. BORN. HOWARD R. (C/S—J-M). Reserve geologist, Tennessee Gas Transmission Co. CALHOUN, GEORGE HENRY. (M). Division mechanical engineer, Shell Oil Co. CRANDALL, JOHN RODERIC. (C/S—J-M). Petroleum engineer, Humble Oil & Refining Co. RAGLAND, DOUGLAS. (C/S—J-M). Assistant chief petroleum engineer, Humble Oil & Refining Co. RASSINIER, EDGAR A. (C/S—J-M). Senior engineer, Phillips Petroleum Co. YALE, WILLIAM DICKINSON. (C/S—J-M). Chief engineer, gas division, The Texas Co.

Kermit—MILLICAN, MARCUS LAVERNE. (J). District engineer, Schlumberger Well Surveying Corp.

Kilgore—BUTTS, JAMES ALVIS, JR. (C/S—J-M). District engineer, Tide Water Associated Oil Co.

Livingston — FAIN, CLEMENT FRANKLIN, III. (C/S—S-J). Trainee, The Texas Co.

Lubbock—COWART, DAVID M. (J). Engineer in charge of location, Schlumberger Well Surveying Corp.

Madisonville—ELLSWORTH, RALPH IRVING. (J). Junior petroleum engineer, American Republics Corp.

Midland—CURTIS, THOMAS M. (C/S—J-M). District engineer, Stanolind Oil & Gas Co. PERUSEK, CYRIL J. (C/S—J-M). Geologist, Residue Research Lab.

SPEERS, FRED HENRY. (C/S—J-M). Petroleum engineer, The Superior Oil Co.

Odessa — CALDER, NORMAN BRUCE. (C/S—S-J). Petroleum engineer, Gulf Oil Corp. HOCKADAY, DONALD EMMETT, JR. (J). Engineer, Kewanee Oil Co. RABE, CHARLES LEONARD. (C/S—J-M). Division exploitation engineer, Shell Oil Co.

Premont — FRANKLIN, LEONARD ODELL. (C/S—S-J). Petroleum engineer, Magnolia Petroleum Co.

Wichita Falls — PARKER, ROBERT GRAY. (C/S—J-M). Assistant district superintendent, Wichita Falls District, Continental Oil Co.

UTAH

Lark — McCONNELL, WALTER FREDRICK. (AM). Mucker, U. S. Smelting Refining & Mining Co.

Magna—RIBOTTO, JOE W. (C/S—J-M). General mill foreman, Utah copper div., Kennecott Copper Corp.

Salt Lake City—apROBERTS GWILYM EVAN. (M). Sales engineer, Cate Equipment Co. SPRAGUE, RODNEY BRYANT. (C/S — J-M). Geologist, American Smelting & Refining Co. SUMSION, HENRY THEODORE (C/S—J-M). Research assistant, Univ. of Utah.

VIRGINIA

Arlington — McMAHON, ALBERT DANIEL. (R,C/S—S-M). Industrial engineer, Munitions Board.

Radford — MARTIN, CLOYD. (M). General manager and superintendent, Great Valley Anthracite Coal Corp.

WASHINGTON

Opportunity — LOWRY, JOHN WILLIAM. (C/S—S-J). Process metallurgist, division of metallurgical research, Permanente Metals Corp.

Tacoma — ANDERSON, KENNETH H. (C/S—J-M). Assistant superintendent, American Smelting & Refining Co.

Wenatchee — HOFF, FRED JAMES. (C/S—J-M). Manager, Central Tractor & Equipment Co.

WISCONSIN

Clintonville—BERKHAHN, ROBERT WILLIAM. (C/S—S-J). Metallurgist, American Smelting & Refining Co.

Milwaukee — KLEMENT, JOHN FRANCIS. (R—M). Chief metallurgist, Ampco Metal, Inc. MANEGOLD, ROBERT LOUIS. (C/S—J-M). President, Dings Magnetic Separator Co.

WYOMING

Casper — BARNETT, JOSEPH H. (C/S—J-M). Division engineer, Stanolind Oil & Gas Co. FALKINGHAM, DONALD HERBERT. (R,C/S—S-M). Petroleum engineer, Stanolind Oil & Gas Co.

ALASKA

Anchorage — NAPPE, LESLIE ERVING. (R,C/S—S-M). Sales engineer, Yukon Equipment, Inc.

BRITISH COLUMBIA

Tulsequah — ROBINSON, GEORGE WILLARD. (C/S—J-M). Mine manager, Polaris-Taku Mining Co.

NORTHWEST TERRITORY

Yellowknife — GROGAN, KENNETH CRAWFORD. (C/S—J-M). Mill superintendent, Giant Yellowknife Gold Mines, Ltd.

ONTARIO

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Ottawa—CONVEY, JOHN (M). Chief metallurgist, Bureau of Mines, Ottawa.

Port Arthur—BARTLEY, MELVILLE WILLIAM. (C/S—J-M). Principal, Lakehead College & Technical Institute.

Schumacher — SMITH, JOHN. (J). Research foreman, production engineering dept., Hollinger Consolidated Gold Mines, Ltd.

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Mazatlan — CONTRINI, ATTILIO S. (R—M). Superintendent, Metalurgica Occidental S. A.

SONORA

Cananea — LOVING, JOHN CLYDE. (C/S—J-M). Mill metallurgist, Cananea Consolidated Copper Co.

BRAZIL

Minas Gerais — FRANK, VIRGIL EVERETT. (C/S—J-M). Assistant mine superintendent, Cia. Vale do Rio Doce.

Sao Paulo—MORAES, ANTONIO ERMIRIO. (J). Engineer, S. A. Industrias Votorantin. MORAES, JOSE E., JR. (C/S—S-J). Engineer, S. A. Industrias Votorantin.

CHILE

Potrerillos — SOBRAL, DANIEL MARTINEZ. (C/S—J-M). Section mine foreman, Andes Copper Mining Co.

PERU

Oroya—BLACK, ANDREW BAXTER. (C/S—J-M). Anode residue plant foreman, Cerro de Pasco Copper Co.

VENEZUELA

Bolivar — WITTMEYER, WILLIAM WOOLSEY. (C/S—S-J). Mine foreman, Guayana Mines, Ltd.

Caracas — ROOKUS, JAMES DUDLEY. (C/S—J-M). Party chief, United Geophysical Co. WIDNER, GEORGE WASHBURN. (J). Petroleum engineer, Creole Petroleum Corp. WISE, M. SMITH, JR. (C/S—J-M). District petroleum engineer, Texas Petroleum Co.

GERMANY

Landgraf Philippotr — GOTTE, AUGUST. (R—M). Works leader, Deutsche Gold & Silver Schneidenstalt.

PORTUGAL

Lisbon — SALEMA GARCAO, JOSE CAETANO. (M). Mine operator, Baralt Tin & Wolfram Co.

SWEDEN

Munkfors — MOLINDER, ANDERS GORAN. (C/S—S-J). Metallurgist, Uddeholm Co., Munkfors Bruk.

UNION OF SOUTH AFRICA

Kimberley — GALLAGHER, WILLIAM STANLEY. (M). Assistant general manager, De Beers Consolidated Mines.

INDIA

Calcutta—AZIM, SYED ANWARUL. (C/S—S-J). Sales supervisor, Caltex (India), Ltd.

JAPAN

Tokyo—HASIGUTI, RYUKITI. (M). Assistant professor of physical metallurgy, Univ. of Tokyo.

NEW SOUTH WALES

Cobar — MORGAN, JOHN PHILIP. (C/S—J-M). Underground superintendent, New Occidental Gold Mines.

Lithgow — WOODWARD, HARRY BERTRAM. (M). Sales representative, Joy Sullivan Machinery Co.

NEW ZEALAND

Dunedin — FITZWILLIAM, JOHN BRUCE HOPE. (C/S—S-J). (Commencing Sept. 1, 1949), Research fellow in mining engineering, Missouri School of Mines & Metallurgy.

STUDENT ASSOCIATES

Elected July 27, 1949

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Gerald A. Cleary....Mich. Min. & Tech.
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Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 601 Continental Building, Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 15, 1949. Any discussion offered thereafter should be in the form of a new paper.

BOTTOM HOLE FLOW SURVEYS FOR DETERMINATION OF FLUID AND GAS MOVEMENTS IN WELLS

C. R. DALE, DALE COMPANY, LOS ANGELES, CALIFORNIA

The need for instruments to measure the movement of fluids and gas in wells has been recognized by engineers for many years. Information regarding flow in the producing interval has a direct bearing on completion practices in new wells and also provides information on the production characteristics of the well. Many hours of engineering time are spent in planning and completing wells but knowledge as to whether or not the original planning has produced the desired results has not always been complete. Many questions such as the following often arise: Why is it that two wells are completed under supposedly identical conditions, yet one well is a good one and the other is a poor one? Are the sands that look the best on the electric log contributing to the production? These and many other conditions in the producing well need to be understood in order to develop more efficient production practices and to improve on methods of completing new wells. It is the purpose of this paper to briefly describe one type of instrument, outline the methods of running the equipment and show the results of surveys made under various conditions. With an understanding of the use of this type of survey its importance can be evaluated in relation to the problems encountered by the operator.

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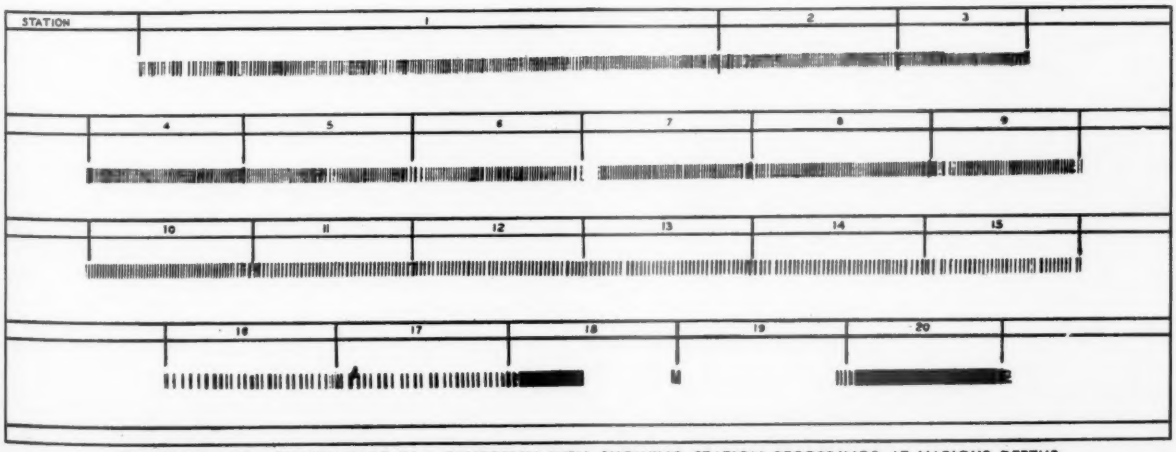
[1] References are given at the end of the paper.

DESCRIPTION OF INSTRUMENT

The instrument is a velocity recorder employing a clock-controlled 16mm film for recording the rpm of an extremely sensitive rotor which is rotated by the flow of fluids or gas in a well. The helical-vaned rotor and shaft, weighing one-half of one ounce are an integral unit exposed to the well fluids and are the only moving parts not enclosed in the fluid-tight housing. No packing or fluid seal of these parts is necessary and the shaft is mounted top and bottom on special jeweled bearings. Fig. A is the lower part of the instrument showing rotor and shaft with the protecting housing sleeve removed. The rpm of the rotor is recorded on the moving film by a combination electrical and optical system. The record is a series of dashes on the film, each dash and space representing twenty (20) revolutions of the rotor. (Film record of survey made in California well showing station recordings at various depths.) As the movement of the film is controlled by the clock the number of dashes and spaces in one minute of film travel represents the rpm of the rotor. The range of the instrument is from 0 to 2,500 rpm. The barrel or housing is 1-11/16 in. OD and seven feet long. Various types of expanding fluid traps are attached to the lower end of the instrument to direct the flow through the 1 in. orifice containing the rotor. The fluid trap for upward flow is shown in Figs. B and C. This assembly consists of eight arms with light spring



FILM RECORD OF A SURVEY MADE IN A CALIFORNIA WELL SHOWING STATION RECORDINGS AT VARIOUS DEPTHS

steel leaves attached to each arm. The arms are free to move in but their outward movement is restricted so that when the trap is open the arms form a circle. Two sizes of these traps are used depending on the velocity to be measured, one 3½ in. and the other 5 in. in diameter. For running in the well the assembly is held in a collapsed position by a restrictor shown in Fig. C. The restrictor is made of a light piece of aluminum tubing with four aluminum arms. In flowing wells the instrument is run in through the tubing into the liner. The instrument is pulled up and the extending arms of the restrictor catch in the perforations or between casing joints and it is pulled off and left in the well. For surveys in pumping wells the instrument is run through the annulus to below the pump with the same type of restrictor. The instrument is pulled up through the liner and the restrictor pulled off by the same procedure as used in flowing wells. For downward flow a fluid trap made of aluminum tubing and light leaf spring steel is used. This fluid trap is made in 3½ in. and 6 in. diameters and is held in position on the instrument sleeve just below the fluid ports by a friction fit as shown in Fig. D. The instrument is run in the well, the readings taken, and the trap is pulled off and left in the well as illustrated in Fig. E.

FIG. A — LOWER PART OF A VELOCITY RECORDER SHOWING ROTOR AND SHAFT WITH PROTECTIVE HOUSING SLEEVE REMOVED

E D B C

FIG. E — TRAP PULLED OFF AND LEFT IN THE WELL AFTER READINGS ARE TAKEN

FIG. D — FLUID TRAP HELD IN POSITION ON THE INSTRUMENT SLEEVE BY FRICTION FIT

FIG. B — FLUID TRAP FOR UPWARD FLOW

FIG. C — FLUID TRAP ASSEMBLY HELD IN COLLAPSED POSITION BY RESTRICTOR

METHODS OF OPERATION

In flowing wells the instrument is run through the tubing (2 in. or larger) under pressure on a measuring line and is lubricated into the well with the same procedure used in running a pressure bomb. For a survey in a flowing well it is necessary that the tubing be above the area to be surveyed.

Surveys in pumping wells are made by running the instrument in the annulus between the casing and tubing. The annular space must be large enough to allow free passage for the instrument but no further preparation of the well is required.

In pumping wells upward fluid movement is recorded if the pump is above the producing zone. However, if the tubing extends into the producing zone, downward flow to the pump can be recorded, and upward flow can be recorded below the bottom of the tubing. In making a survey for upward flow the instrument is stopped at various depths called stations. The first station is usually in the blank section above the perforations where the velocity of all fluids and gas moving past this point is recorded. The instrument is then lowered to the next station, a reading taken there, and so on to the lowest depth that can be reached. For downward flow the same procedure is used except that an inverted fluid trap is used.

INTERPRETATION OF SURVEYS

All precision measurements in wells require some interpretation to get the true picture, and flow surveys are no exception. In making interpretation of surveys made inside of perforated pipe it must be remembered that the fluid may not be entering the perforations directly opposite the formation that is contributing the production. In most wells surveyed to date however, the production seems to be coming through the perforations directly opposite the contributing sands. The results of surveys in a number of wells indicate the flow in machine cut perforated pipe is more steady than in gun perforated

pipe. In this case it is the writer's opinion that the recorded variations of rpm is due to the fewer perforations and the fluid jetting through them. In some wells the flow in the producing zone is intermittent or irregular and several runs may be required to catch a period of steady movement of fluid. Changes in viscosity and density of the fluid effect the rpm of the rotor. For example a steady flow of oil may move up the hole to a point of gas entry. From this point the rising fluid has less density and viscosity, therefore less efficiency in turning the rotor. This results in a decrease in rpm at the point of gas entry. Temperature and pressure surveys are used in conjunction with the flow surveys and have aided a great deal in confirming interpretation. Although bottom hole flow surveys are a comparative new work and much experience is yet to be gained, only a few wells of the large number surveyed have presented a difficult problem of interpretation.

SATISFACTORY WELL FLOW CONDITIONS

The well shown in Fig. 1 was completed with oil base mud and a 5½ in. liner was run into the 6⅛-in. hole after the well had been conditioned. Two-inch tubing was landed at 4,915 ft with a 1½ in. tail to 5,635 ft. The tail pipe was retrieved for the flow survey and the well allowed to flow through the casing to obtain a steadied flow than could be maintained through the tubing. The well was producing 97 barrels per

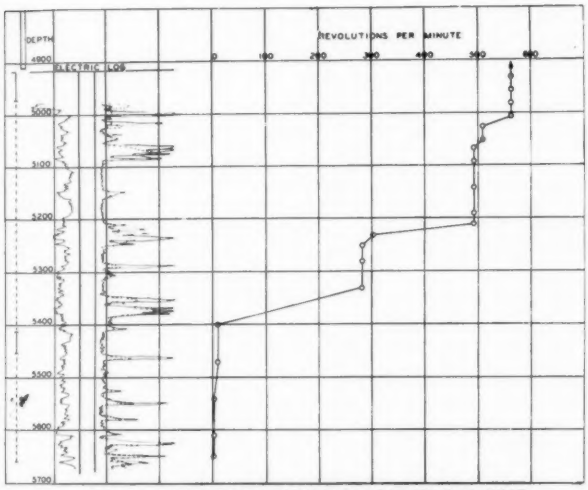


FIG. 1 — ELECTRIC LOG AND FLOW SURVEY SHOWING SATISFACTORY WELL CONDITIONS

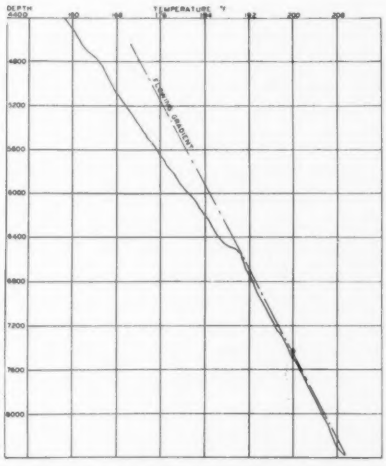


FIG. 2 — OIL AND GAS MIGRATION SHOWN BY TEMPERATURE SURVEY

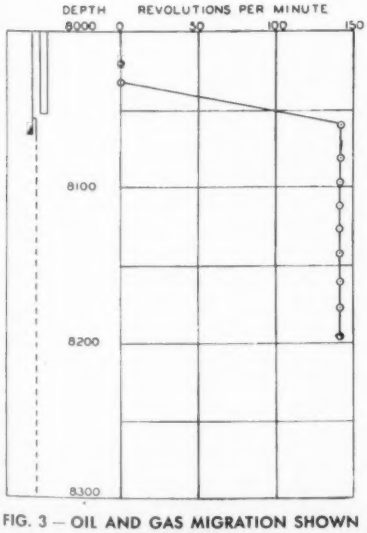


FIG. 3 — OIL AND GAS MIGRATION SHOWN BY FLOW SURVEY

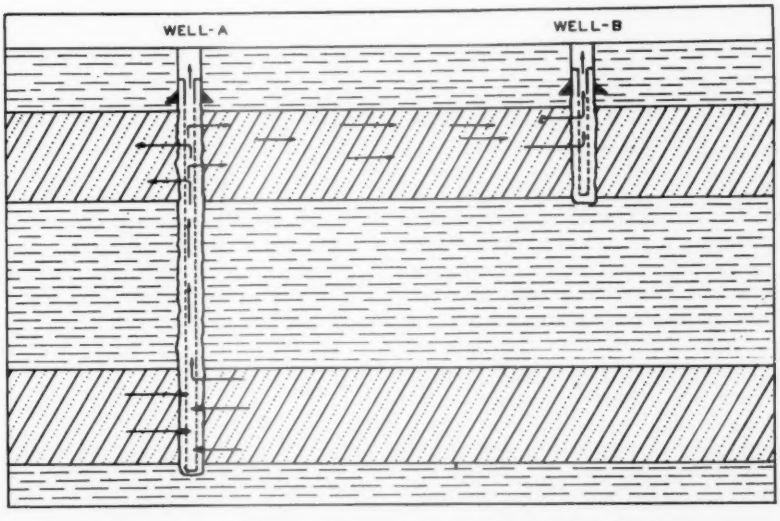


FIG. 4 — CONDITIONS FAVORABLE TO OIL AND GAS MIGRATION

day of 28 API gravity oil with 106 Mcf of gas. The electric log shows three oil sands of considerable width each separated from the other by approximately 100 ft of shale. The flow survey indicates all three sands are contributing production. Ten rpm recorded between 5,400 ft and 5,470 ft was probably caused by a small amount of gas flowing through fluid standing below 5,400 ft.

The lower 300 ft of formation that was not contributing production has productive sands that would probably produce if they were separated from the three upper sands. It is also possible that these sands may contribute production later on as pressures decline. One of the most important uses of this type of survey is to determine if sands that do not contribute production in the early life of the well will produce as the pressures subsequently become lower.

In several wells with long intervals it has been found that only a fraction of the formation in the upper part of the zone contributes any production. Attempts have been made to increase the productive area by producing the wells at a high rate, thereby reducing the pressure against the sands. In these wells there was no change in the producing areas.

With mud, water or dense fluids against the face of a sand for a long period of time it is possible that the sand will remain ineffective even after the pressures decline. For this reason knowledge of the areas contributing production in the early life of a well is quite important. To survey one well in a field and find conditions as satisfactory as they were in this well (Fig. 1) might lead an operator to feel that all his wells were in the same favorable conditions. This may not be true.

OIL AND GAS MIGRATION

Migration of fluids and gas from one sand to another or from the producing interval into formations that are supposed to be excluded from the well is a condition that is difficult to detect by normal operating procedure. Where the migration of oil takes place into dry or depleted sands it is possible that a substantial part will not be recovered. Casing failure may occur allowing large quantities of oil and gas to escape without causing any appreciable change in surface operating pressures. Fig. 2, a temperature survey and Fig. 3, a flow survey, were made in a well where this condition existed.

A flow survey was first made with the well flowing and indicated upward migration. The well was shut in and the flow survey, Fig. 3, was run. This clearly showed upward movement from the producing interval to the bottom of the tubing. Readings taken in the tubing did not record any fluid movement. From the results of the survey it was quite evident that the fluid was flowing up through the annulus between the tubing and casing.

The temperature survey was then run (Fig. 2) in the tubing with the well shut in. This survey disclosed a flowing temperature gradient to 6,500 ft and a change that approached the shut-in temperature gradient above this point. It also indicated that oil was flowing up through the annulus for 1,700 ft and migrating through a hole in the casing at 6,550 ft. Other wells in the area were producing from this same depth. Although it is probable that the oil escaping from this well will be recovered in the wells producing from the thief sand, if a dry sand or formation of high porosity existed opposite the hole in the casing the oil would have been permanently lost.

The extent to which migration is taking place from one sand to another

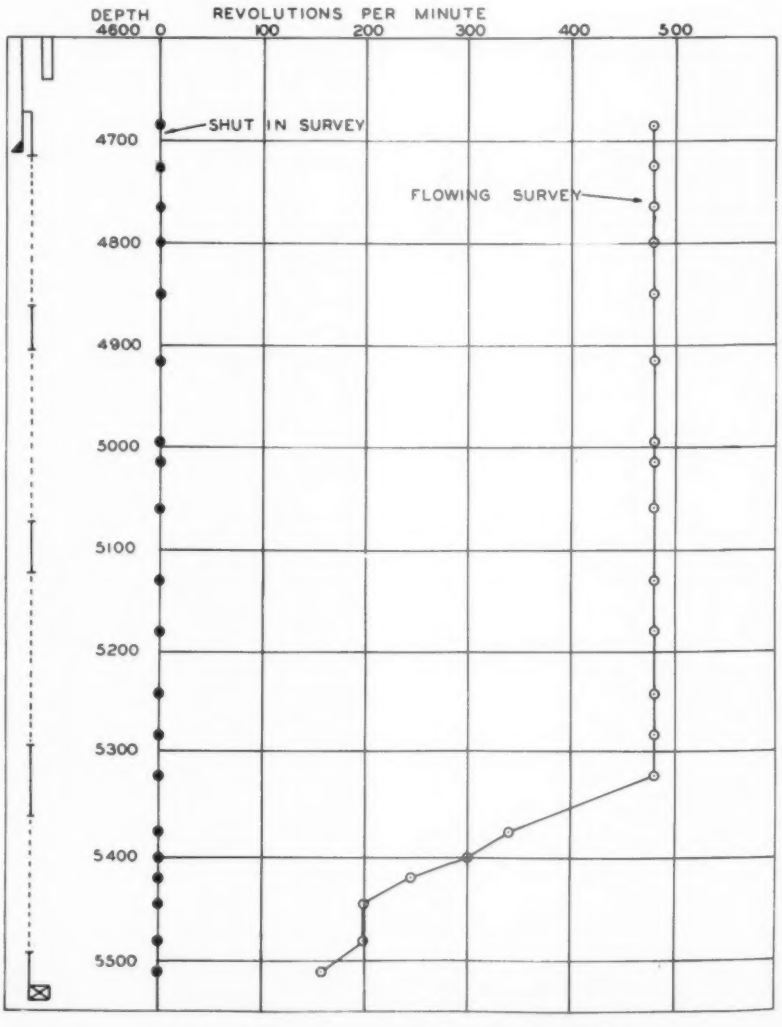


FIG. 5 — FLOW SURVEY SHOWING BRIDGE PLUG LEAKING

is partly the result of the way in which the various wells in the field are completed. Where zones of different pressures are included in a single well and separated by mechanical means the failure of the separating device may lead to migration of oil and gas from one zone to another. The manner in which wells are completed can set up conditions that are favorable to migration. This is illustrated in the sketch (Fig. 4) where Well A is completed in two zones while Well B is completed in the upper zone only. The lower zone of Well A may be contributing a substantial part of the production of Well B, and of other wells producing from only the upper zone.

The study of migration of fluids and gas in wells encompasses a wide field. Considerable experience over a period of time will be required to explain fully the unusual conditions found in many wells.

BRIDGE PLUG LEAKING

In the well represented in Fig. 5, the operator knew that something was wrong because the pressures were abnormally high for the zones above 5,500 ft. Also the temperature at 5,500 ft was 226°F, while in an adjacent well at this depth the geothermal temperature was approximately 214°F. The flow survey revealed that the plug in the blank section below 5,500 ft was leaking. The plug had been placed to exclude production from lower zones. A survey was made with the well shut in to determine if fluid was moving into the lower pressure zones above the plug, but no movement was indicated. Although production was coming from the perforated interval 5,360 ft to 5,495 ft when the well was producing it seemed quite possible that failure of the formations opposite the upper three sets of perforations to produce was due to high pressure from the lower zone. The pressures and temperatures recorded in this well were substantial evidence that the plug was leaking, and the flow survey, in addition to confirming this fact, also showed the failure of the three upper sets of perforations to contribute to the well production.

WELL COMPLETED WITH 3 IN. LINER IN 10⅝ IN. HOLE

In the well shown in Fig. 6 a three-inch perforated liner was hung on 2½

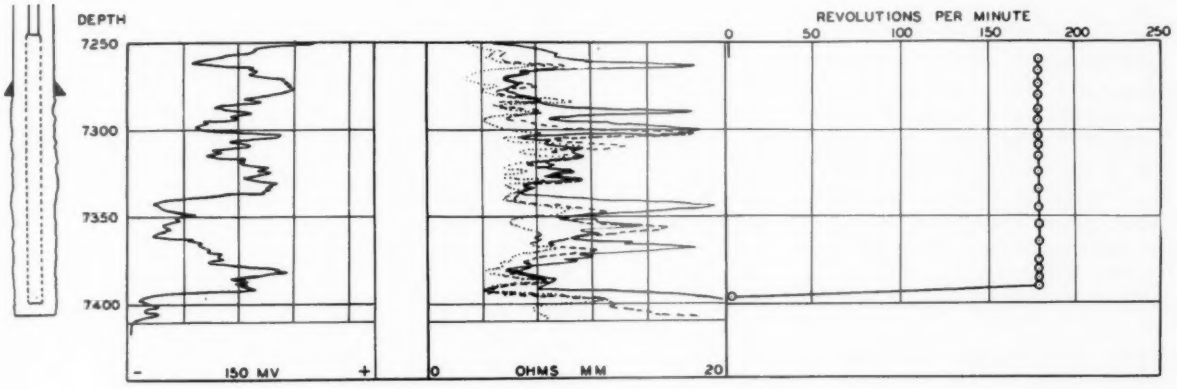


FIG. 6 — WELL PRODUCING FROM LOWER SANDS ONLY

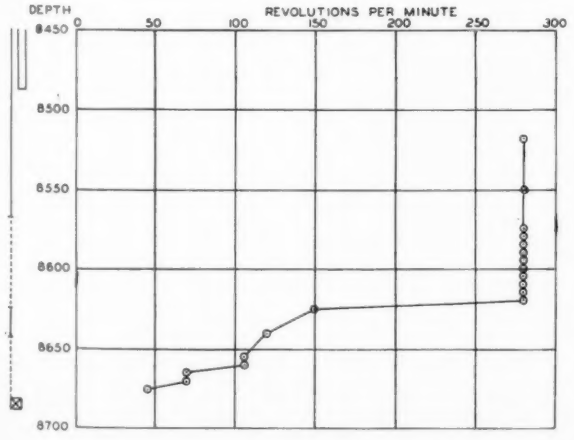


FIG. 7 — FLOW SURVEY SHOWING TWO POINTS OF WATER ENTRY

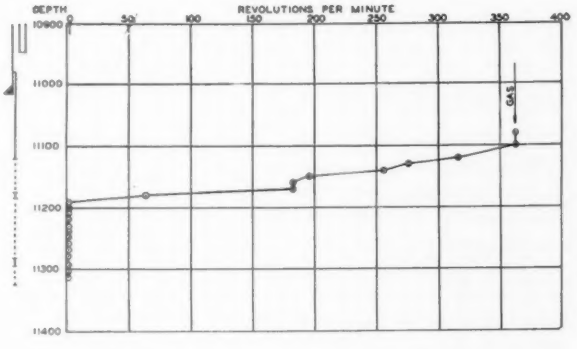


FIG. 8 — FLOW SURVEY OF A GAS INJECTION WELL

in. tubing in a 10⅝ in. hole. The operator had originally planned to pull the liner after a test, but the results of the flow survey and the satisfactory performance of the well show that the liner should be left in place. The flow survey indicates that all the production is coming from the sand in the bottom fifteen feet of the fell and operating data confirms this finding. A pressure traverse recorded a flowing gradient to the bottom of the well. Adjacent wells completed in only the lower sand affected this well when produced at a high rate indicating that it, too, was producing from the lower sand. It will be noted that here again sands shown on the electric log are not contributing to the production of the well.

FLOW SURVEY — LOCATE WATER SOURCE

The full extent to which flow surveys can be used in locating water sources in wells has not as yet been determined. Where a well is producing all water the method can be applied very successfully. In a well (Fig. 7) 110 barrels of water and 3 barrels of oil per day were being gas-lifted through the tubing. The flow survey indicated water entering at the blank section 8,627 ft to 8,645 ft, and at another point below 8,660 ft. The effective depth of the well was 8,676 ft. These results confirmed a water location survey that had previously located a major source of water at the top of the blank section and a minor source at the bottom of the well. At the lowest station only 45 rpm was recorded on the flow survey, representing a fluid velocity of less than one foot per minute.

GAS-INJECTION WELL

At the time of the survey of a gas-injection well, Fig. 8, four million feet of gas was being injected through the tubing with a surface injection pressure of approximately 400 lbs. The flow survey was made in two runs. On the first run readings were taken at every other station plotted in Fig. 8, and on the second survey at the stations between those of the first run. This procedure shows how closely two runs check when the conditions remain constant in the well. Temperature surveys indicated that there were only a few feet of fluid in the well and that some gas was going out in the lower part of the second set of perforations. From the flow survey it is quite evident that most of the gas was going into the formation opposite the top of perforations and just below the blank at 11,190 ft. The gas indicated moving downward below this point on the temperature survey was such a small amount that it was impossible to record it on the flow survey.

LOCATING GAS ENTRY

The well represented in Fig. 9 was producing 3 barrels of oil and one million feet of gas at the time the flow and temperature surveys were made. Both surveys show the gas coming from the upper set of perforations. A pressure traverse was made which recorded a gas column to the blank section, 3,379 ft-3,412 ft and a fluid gradient below the blank. The blank section was cemented with plastic and tested for shut-off. A packer was then run in on tubing and set in the blank section. The upper set of perforations was then tested by flowing through the annulus between the tubing and casing. For several days the well produced considerable oil and then went to gas, indicating that oil had migrated into the gas sand during the shut-in period.

It had been found that the use of continuously recorded temperature surveys is a good check and in many cases confirms information obtained on the flow survey.

CONCLUSION

In this brief paper it is not possible to set forth the applications and limitations of bottom hole flow surveys. The examples given illustrate a few applications and will serve to suggest many others.

The bottom hole flow survey supplies an important link in the chain of information necessary for complete understanding of the conditions existing in the producing wells. The data can be obtained with a minimum of equipment; no great amount of time is required for the field work; the average survey requires no special knowledge for interpretation. Used in conjunction with other precision measurements bottom hole flow surveys give the engineer a more complete picture of conditions existing in the well. ★ ★ ★

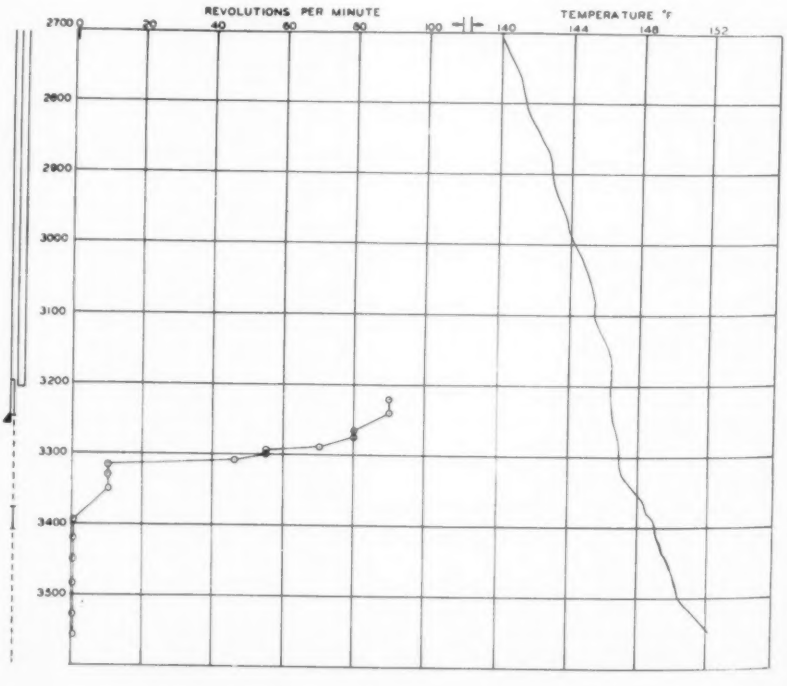


FIG. 9 — FLOW AND TEMPERATURE SURVEYS SHOWING GAS ENTRY

THE EFFECT OF WELL SPACING AND DRAWDOWN ON RECOVERY FROM INTERNAL GAS DRIVE RESERVOIRS*

RAYMOND G. LOPER, JUNIOR MEMBER AIME, AND **JOHN C. CALHOUN, JR.,** MEMBER AIME
PETROLEUM ENGINEERING DEPARTMENT, UNIVERSITY OF OKLAHOMA, NORMAN, OKLAHOMA

ABSTRACT

Theoretical calculations for the decline of pressure and the variation of instantaneous producing gas-oil ratio with increased cumulative production have been made for reservoir systems under various producing drawdown values and for various spacings. These variables have been included by a modification of previously published techniques. This consists essentially of utilizing a radial system flowing gas and oil in a succession of steady state calculations. The results of the calculations do not show any variation in the predicted behavior of the internal gas drive reservoir when either the drawdown or the spacing are changed.

* A summary of material presented by Raymond G. Loper to the Graduate Faculty, Univ. of Oklahoma, in partial fulfillment of the master's degree.

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INTRODUCTION

The prediction of performance on an internal gas drive reservoir has been presented by various authors.[1,2,3] These predictions are in the form of a pressure decline and an instantaneous producing gas-oil ratio as a function of cumulative oil withdrawal. In making these predictions a basic assumption has been that the saturation of the reservoir is uniform throughout at any time, or that the pressure differential imposed on the reservoir system is zero. Because of these assumptions the validity of such predictions has been questioned. Their application to actual systems, where saturations are not uniform and where producing differentials exist, has been a hazardous procedure.

The authors cited[1,2,3] have used different methods of approach to the derivation of equations for making their predictions and for arriving at a solution of both equations, but basically the same relationships are utilized in each case. In all instances the instantaneous producing gas-oil ratio is calculated from the equation:

$$R = \frac{k_g}{k_o}\frac{\mu_o}{\mu_g}\frac{\beta}{v} + s \quad . \quad . \quad . \quad . \quad (1)$$

In utilizing this equation an average reservoir pressure and an average reservoir saturation must be known, the former to define β, v, s, and μ_o/μ_g and the latter to define k_g/k_o. Predictions can be made, therefore, only for the conditions of a uniform reservoir saturation and a uniform reservoir pressure.

This restriction of requiring a uniform oil saturation can be resolved by applying two-phase steady state flow for the radial system to the reservoir's history. Radial steady state flow is defined when the ratio of phases flowing,

Nomenclature is listed at close of paper.
[1] References are given at end of paper.

TABLE Ia
TYPICAL CALCULATION OF PREDICTED QUANTITIES
Conditions: $r_w = 0.25$ ft.; $r_e = 750$ ft.; $(P_e - P_w) = 1{,}000$ psi; 39° API Oil
CALCULATION NO. 2 FOR TIME WHEN $P_e = 2{,}300$ psia
Assumed $R_i = 2{,}100$

P_x	β	v	s	μ_o/μ_g	μ_o	k_g/k_o	S_o	k_o/k	$\frac{k_o/k}{\mu_o\beta}$	$\int_{1300}^{P_x} \frac{k_o/k}{\mu_o\beta}dp$	$\frac{\ln r_x}{r_w}$	r_x
						(a)					(b)	
2300	1.463	.00126	761	18.6	.356	.0620	.7032	.544	1.044	926.0	8.01	750
2200	1.452	.00134	737	19.6	.364	.0639	.7010	.537	1.016	823.0	7.11	308
2100	1.441	.00140	713	20.6	.373	.0654	.6995	.534	0.993	722.6	6.24	130
2000	1.431	.00148	689	21.6	.381	.0676	.6970	.528	0.968	624.6	5.40	55.5
1900	1.420	.00155	664	22.6	.390	.0694	.6950	.526	0.950	528.7	4.57	24.2
1800	1.408	.00165	640	23.7	.400	.0722	.6923	.523	0.929	435.2	3.76	10.8
1700	1.397	.00173	616	24.8	.407	.0741	.6905	.518	0.911	343.2	2.96	4.8
1600	1.386	.00185	592	26.0	.416	.0774	.6870	.510	0.885	253.4	2.19	2.2
1500	1.375	.00200	568	27.1	.425	.0822	.6825	.502	0.859	166.2	1.44	1.05
1400	1.364	.00217	544	28.3	.435	.0875	.6780	.492	0.829	81.8	0.71	
1300	1.353	.00235	520	29.4	.444	.0933	.6730	.484	0.806	0	0	

(a) Calculated from Equation (1)
(b) Calculated from Equation (3)

the pressures imposed, and the dimensions of the system are fixed. The system then possesses definite saturation and pressure distributions, both of which can be calculated.

The procedure to be outlined below, therefore, consists of fixing the gas-oil ratio, the pressure drawdown, and spacing (or drainage radius) for a radial system which is flowing oil and gas of known characteristics. The saturation distribution calculated for the system then permits the determination of stock tank oil removed from the system, and the pressure distribution calculated for the system permits the determination of the average pressure of the system. The gas oil ratio chosen, the stock tank oil produced, and the average pressure on the reservoir must then balance according to material balance concepts. If a balance is not obtained, trial changes of the fixed quantities are made and the calculation repeated until a balance is reached. By making a series of such calculations, the history of the reservoir can be determined, under whatever spacing and pressure drawdown values are assigned.

RADIAL, TWO-PHASE STEADY STATE FLOW

The development of Darcy's law as applied to a radial system for oil and gas mixtures under steady state flow has been given in the literature.[4] Steady state implies not only constancy of pressure with time but also constancy of the relative amounts of gas and oil flowing at any place in the system. The most convenient place at which to fix the relative amounts of oil and gas is at the well radius, where they can correspond to an instantaneous producing gas-oil raio.

For a radial system with an assigned value of instantaneous producing ratio, R, the flow of oil is given by:

$$Q_o = \frac{7.07\ kh}{\ln \frac{r_e}{r_w}} \int_{P_w}^{P_e} \frac{k_o/k\ dp}{\mu_o \beta} \quad . \quad (2)$$

Since this flow can be expressed across a fraction of the system from well radius r_w to any radius r_x, as well as across the whole system, the following is true:

TABLE Ib

Radii of Volume Increment in Feet	Fraction of Total Volume	Average Pressure for Increment	Volumetrically Weighted Pressure	Average S_o for Increment	Average β for Increment	Volumetrically Weighted S_o/β
308 —750	.8313	2250	1870	.7021	1.4575	.4004
130 —308	.1387	2150	298	.7003	1.4465	.0671
55.5—130	.0245	2050	50	.6982	1.4360	.0119
24.2— 55.5	.0044	1950	9	.6960	1.4255	.0021
10.8— 24.2	.0009	1850	2	.6937	1.4140	.0004
4.8— 10.8	.0003	1750	1	.6914	1.4025	.0002
	1.0001		2230= avg. pres.			.4821

Initial value of $S_o = .80$;

Equivalent initial stock tank oil $= \frac{.80}{.154} = .5195$;

$$\left(\frac{n_1}{N}\right)_{avg} = \frac{.5195 - .4821}{.5195} = .0720$$

From previous calculation the following values are known:

$R_{1-1} = 1180$ $\qquad u_o = 1.54$

$\frac{n_{1-1}}{N} = .0244$ $\qquad s_o = 930$

From P = 2230 the following values are found:

$u_1 = 1.6984$ $\qquad v_1 = .00131$

From calculation for previous step:

$$\sum_{i=1}^{i=i-1} \left(\frac{R_{i-1} + R_i}{2}\right)\left(\frac{n_i}{N} \quad \frac{n_{i-1}}{N}\right) = 25.74$$

Substituting the above known values in Equation (4) and solving for R_i:

$$\frac{219.16 - 1912\ (.7020)}{.0720 - .0244} = 1713 = \text{calc. value of } R_i$$

Since $1{,}713 \neq 2{,}100$ Repeat Calculation by assuming $R_i = 2{,}045$

TABLE IIa
Summary of All Calculations 39° API Oil

Curve Identification No. Fig. 7	Assumed Conditions	Predicted Quantities	Calculation No. 1	2	3	4	5	6	7
1	$(P_e - P_w) = 0$ S_o Uniform	P	2772	2275	1775	1275	775	450	200
		R	1108	1966	3125	4525	5300	4695	3840
		n/N	.0208	.0640	.1045	.1408	.1733	.1948	.2278
4	$r_e = 300$ ft. $(P_e - P_w) = 1000$ psi	Pavg	2716	2223	1726	1230	743	448	250
		R	1190	2060	3250	4653	5316	4730	4050
		(n/N)avg	.0255	.0686	.1099	.1454	.1767	.1979	.2240
2	$r_e = 750$ ft. $(P_e - P_w) = 1000$ psi	Pavg	2728	2230	1730	1232	745	449	251
		R	1180	2045	3240	4625	5375	4745	3625
		(n/N)avg	.0244	.0680	.1085	.1437	.1778	.1985	.2256
3	$r_e = 1500$ ft. $(P_e - P_w) = 1000$ psi	Pavg	2735	2233	1734	1237	745	449	250
		R	1150	2047	3225	4560	5373	4738	3950
		(n/N)avg	.0240	.0681	.1088	.1488	.1768	.1975	.2230
5	$r_e = 750$ ft. $(P_e - P_w) = 200$ psi	Pavg	2278	2278	1778	1278	779	479	279
		R	1096	1979	3100	4505	5297	4905	3960
		(n/N)avg	.0202	.0638	.1051	.1412	.1736	.1944	.2187
6	$r_e = 750$ ft. $(P_e - P_w) = 1000$ psi Using Eq. (5)	Pavg	2729	2228	1729	1236	761	472	279
		R	1190	2055	3230	4640	5255	5050	3800
		(n/N)avg	.0262	.0682	.1080	.1437	.1745	.1970	.2151

TABLE IIb
Summary of All Calculations 30° API Oil

Assumed Conditions	Predicted Quantities	1	2	3	4	5	6	7
$(P_e - P_w) = 0$ S_o Uniform	P	2724	2230	1735	1234	746	449	250
	R	1365	2960	5315	7390	8530	7085	4895
	n/N	.0237	.0543	.0903	.1015	.1188	.1265	.1347
$r_e = 750$ ft. $(P_e - P_w) = 1000$ psi	P	2724	2231	1735	1234	746	449	250
	R	1313	3005	5495	7235	8760	7000	5150
	(n/N)avg	.0241	.0547	.0905	.1018	.1190	.1264	.1348

$$\frac{\ln \frac{r_x}{r_w}}{\ln \frac{r_e}{r_w}} = \frac{\int_{P_w}^{P_x} \frac{k_o/k}{\mu_o \beta} dp}{\int_{P_w}^{P_e} \frac{k_o/k}{\mu_o \beta} dp} \quad \ldots \quad (3)$$

Equation (3) is used to obtain the values of pressure and radius which correspond throughout the system. The calculation of the integral quantities in equation (3) is made by use of equation (1) as given in the following paragraph.

For an assigned value of R, k_g/k_o can be calculated if the pressure is fixed. From k_g/k_o a value of k_o/k can be found. Therefore, the value of the quantity $\frac{k_o/k}{\mu_o \beta}$ can be calculated as a function of pressure. The variation is valid only for the R value assigned. By plotting $\frac{k_o/k}{\mu_o \beta}$ versus pressure the value of the integral $\int_{P_w}^{P_e} \frac{k_o/k}{\mu_o \beta} dp$ is then made definite as values of P_e and P_w are chosen. The first ten columns of Table Ia give a calculation of $\frac{k_o/k}{\mu_o \beta}$ between pressures of 1,300 psia and 2,300 psia for a gas-oil ratio of 2,100 cubic feet per barrel. The numerical value of the integral $\int_{P_w}^{P_x} \frac{k_o/k}{\mu_o/\beta} dp$ is determined from equation (3) when values of r_x, r_e, and r_w are chosen. Fixing the value of the integral fixes P_x, the pressure which corresponds to the radius r_x. It is a simpler calculation to work this process in reverse by choosing P_x. Then a value of r_x can be calculated from equation (3).

The saturation existing at this pressure and radius can be determined by referring to the value of k_o/k as determined from $\frac{k_o/k}{\mu_o \beta}$ versus pressure from which the integral values of Table Ia were determined. Fig. 1 is the plot of $\frac{k_o/k}{\mu_o \beta}$ versus pressure from Table Ia, and Fig. 2 is the variation of pressure versus radius and saturation versus radius calculated from the same information.

In summary, therefore, the steady state situation is completely defined by the quantities chosen for r_e, r_w, P_e, P_w, and R, from which the saturation and pressure distributions of Fig. 2 have been calculated. A similar calculation can be made for any set of chosen quantities.

CALCULATION OF PRESSURE DECLINE

In utilizing the above steady state character to predict reservoir performance, systems with different drainage radii and different $(P_e - P_w)$ values were chosen. The equations for predicting performance are essentially those used by Tarner.[2] Gas-oil ratio values were at first estimated and both pressure and saturation distributions within the producing system were calculated. If the chosen gas-oil ratio and the calculated pressure and saturation values did not check by material balance, a new gas-oil ratio was estimated and the process repeated.

The equation expressing a balance between pressure, stock tank production, and producing gas-oil ratio is:

$$\frac{(u_i - u_o) - \frac{n_i}{N} u_i + \frac{n_i}{N} s_o v_i}{v_i} = \sum_{i=1}^{i=i} \left(\frac{R_i + R_{i-1}}{2} \right) \left(\frac{n_i}{N} - \frac{n_{i-1}}{N} \right) \quad (4)$$

which equation is valid for the assumptions of no water encroachment, no gas

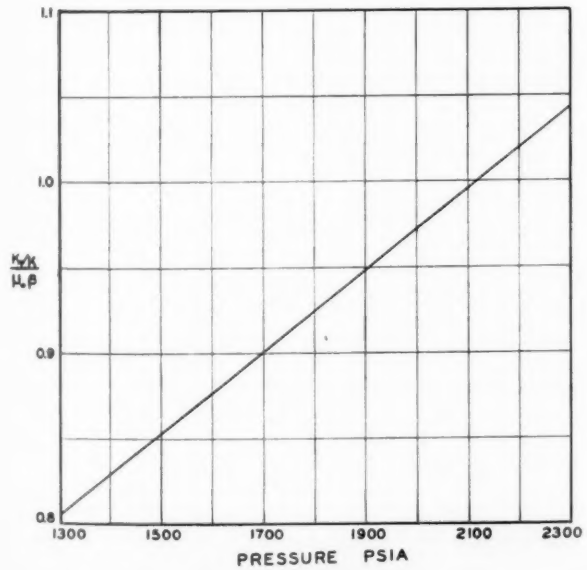

FIG. 1 — VARIATION OF $\frac{k_o/k}{\mu_o \beta}$ WITH PRESSURE

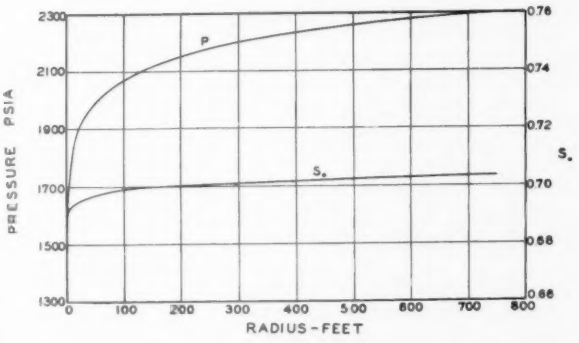

FIG. 2 — DISTRIBUTION OF PRESSURE AND OIL SATURATION WITHIN THE RADIAL FLOW SYSTEM

cap, and no gas reinjection. This equation is simply a statement of the equality of total produced gas obtained by two independent methods. The left-hand side gives total produced gas as found in the basic material balance equation. The right-hand side gives the total produced gas as found by the area under a plot of producing gas-oil ratio versus cumulative oil production.

To arrive at a set of values for $\frac{n_i}{N}$, P_i, and R_i to balance in the above equation the procedure was as follows: (this procedure is tabulated in Table I)

(1) Values of r_e, r_w, and $(P_e - P_w)$ were chosen for the particular system.

(2) A value of R_i was chosen and the variation of $\frac{k_o/k}{\mu_o \beta}$ with pressure values between P_e and P_w was calculated according to equation (1).

(3) Values of P_x between P_e and P_w were chosen and used to calculate r_x values according to equation (3).

(4) S_o values were calculated for each value of r_x by use of the pressure values found at r_x, the quantity $\frac{k_o/k}{\mu_o \beta}$ at that pressure, and the dependence of k_o/k on saturation.

These first four steps are essentially calculation of the steady state system as outlined above and tabulated in Table Ia.

(5) Each value of reservoir saturation S_o was converted to an equivalent stock tank oil value by dividing by the value of β for the pressure existing at that saturation point. An average value of stock tank oil remaining in the entire system was obtained by averaging these point values volumetrically over the system, and subtracting the average from the total original oil in place to give n_i/N. This is shown in Table Ib.

(6) An average pressure for the entire system was obtained by averaging the point values volumetrically over the entire system. This is shown in Table Ib.

(7) Values for R_i . n_i/N, and for fluid characteristics as determined by the average pressure were substituted in equation (4) to obtain a balance. If a balance was not obtained, a new value of R_i was chosen and the steps from (2) to (7) were repeated.

As indicated by equation (4) the subscript i refers to any time point in the reservoir's history. The complete history was determined by a succession of such calculations, choosing in each case the time when the pressure at the drainage radius had fallen to some convenient value.

The above calculation was applied to three different well systems with $r_e = 300$ ft, $r_e = 750$ ft, and $r_e = 1{,}500$ ft (corresponding roughly to spacings of 10, 40, and 160 acres) and for values

TABLE III
Calculation Using Increment Reservoirs

CONDITIONS: $r_e = 750$ ft; $r_w = .25$ ft; $(P_e - P_w) = 1000$ psi
Calculations for time when $P_e = 2300$ psia[3]
Assume $R_i = 2040$

Radii of Increment	f_x	Average Pressure of Increment	Average S_o	u_{ix}	$\frac{n_{ix}}{N}$	$\frac{f_x(u_{ix}-u_o)+\frac{n_{ix}}{N}(v_{ix}s_o-u_{ix})}{v_{ix}}$
		(a)	(a)		(b)(c)	
315 —850	.8236	2250	.7055	1.6928	.05628	75.862
135 —315	.1440	2150	.7034	1.7233	.00920	15.200
60 —135	.0260	2050	.7015	1.7681	.00155	3.641
25 — 60	.0053	1950	.6988	1.8050	.00030	.853
11 — 25	.0009	1850	.6967	1.8460	.00005	.163
5 — 11	.0002	1750	.6943	1.9142		
2.5— 5						
1 — 2.5						
0.5— 1.0						
.25— 0.5					$\frac{n_i}{N} = .06738$	
						95.719

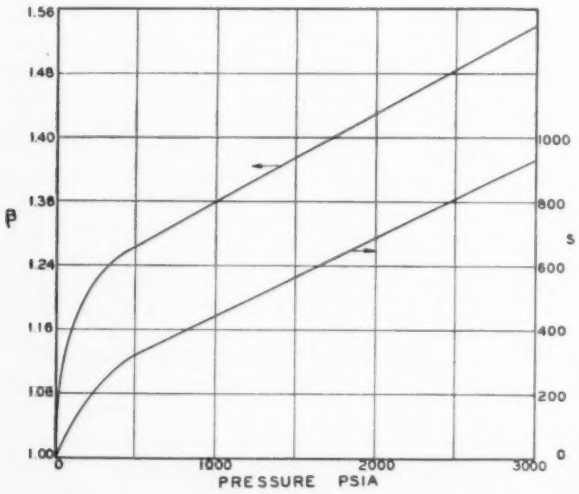

FIG. 3 — FORMATION VOLUME FACTOR AND GAS SOLUBILITY CHARACTERISTICS OF 39° API RESERVOIR OIL

From previous calculation: $\frac{n_{i-1}}{N} = .02615$

$R_{i-1} = 1{,}190$

$$\sum_{i=1}^{i=i-1} \left(\frac{R_i + R_{i-1}}{2}\right)\left(\frac{n_i}{N} - \frac{n_{i-1}}{N}\right) = 27.72$$

$$27.72 + \frac{(2{,}040 + 1{,}190)}{2}(.06738 - .02615) = 94.31$$

Since $94.31 \neq 95.72$ Repeat Calculation using $R_i = 2{,}055$

(a) Determined by procedure shown in Table Ia

(b) $$\frac{n_{ix}}{N} = \frac{\left(.5195 - \frac{S_o}{\beta}\right) f_x}{.5195}$$

(c) $$\frac{n_i}{N} = \sum_{x=1}^{x=10} \frac{n_{ix}}{N}$$

of $(P_e - P_w)$ equal to 200 pounds and 1,000 pounds. Fluid characteristics approximating a 39°API crude and a 30°API crude were used in two different sets of calculations. Calculation was also made of the reservoir predictions as ordinarily carried out for uniform reservoir saturation and zero drawdown conditions to use as a basis for comparison.

Tabulation of a typical calculation is given in Table I, and results of all calculations are listed in Table II. In every case original reservoir pressure was chosen as 3,000 psia and the connate water was chosen as 20 per cent. Variations of β and s with pressure (as used in all calculations with the exception of these marked 30° API) are given in Fig. 3. Dependence of the quantity v on pressure is given by Fig. 4. Variation of μ_o and μ_o/μ_g with pressure are shown in Fig. 5. The dependence of k_o/k with gas saturation is shown in Fig. 6, and the dependence of k_g/k_o with gas saturation in Fig. 7. Fig. 6 is taken from Leverett and Lewis[6] (their Fig. 9) for 15-25 per cent connate water. Fig. 7 was computed using the k_o/k values of Fig. 6 and an assumed k_g/k curve such that gas flow would begin as soon as gas formed in the flow channels. Even though this k_g/k_o curve may not be identical with that measured by actual experiment the same curve was used for calculations assuming zero drawdown and finite drawdown. The results reported therefore, should reflect variation in the assumed variables rather than in the k_g/k_o curve.

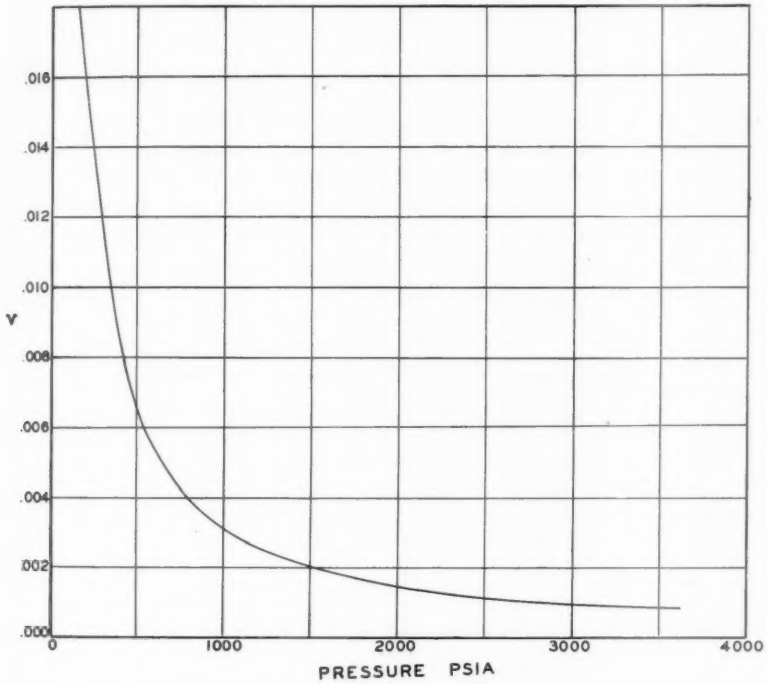

FIG. 4 — GAS CONVERSION FACTOR-BARRELS RESERVOIR GAS SPACE PER STANDARD CUBIC FOOT

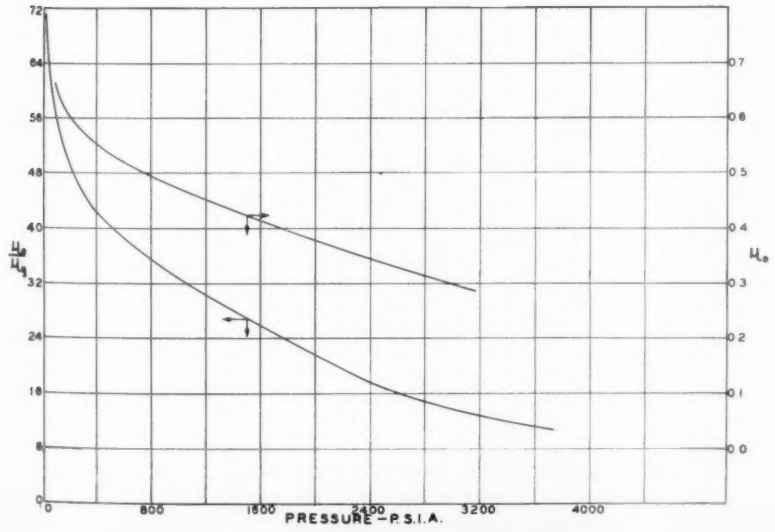

FIG. 5 — VISCOSITY CHARACTERISTICS OF RESERVOIR OIL AND GAS

Fig. 8 shows the predicted results graphically. It is noted that the calculated variation of pressure and instantaneous producing gas-oil ratio with withdrawals is equivalent, for all circumstances calculated, to that determined using the simple equilibrium conditions. This leads to the conclusion that the recovery to be derived from an internally gas driven reservoir is a function only of the fluid properties and flow properties. The economic rate at which these withdrawals occur has been ignored in this analysis. Should any variation of time and abandonment be necessitated by circumstances which give low rates of withdrawal the ultimate recovery would be variable. This approach has been treated by another author.[5]

CALCULATION AS A SERIES OF SEPARATE RESERVOIRS

In considering possible shortcomings to the analysis outlined, it was thought that the method of averaging stock tank saturation and pressure over the drainage system and using fluid characteristics at the average pressure for substitution in the material balance equation might give an erroneous picture. Therefore, the analysis was extended to consider the chosen radial system as a

number of separate reservoirs each at its own pressure and saturation but with a common instantaneous producing gas-oil ratio. To do this, the system was first divided into a number of increments of assigned radii, the volumes of which were denoted as fractions of the total, f_1, f_2, f_3, . . . f_x, x denoting any given volume increment. Ten volume increments were used. The material balance equation can be shown to apply in summation to the group of increment reservoirs to give the following:

$$\frac{\sum_{x=1}^{x=10} f_x\,(u_{ix}-u_o)+\frac{n_{ix}}{N}\,s_o\,v_{ix}-\frac{n_{ix}}{N}\,u_{ix}}{v_{ix}} = \sum_{i=1}^{i=i}\left(\frac{R_i-R_{i-1}}{2}\right)\left(\frac{n_i-n_{i-1}}{N}\right) \quad (5)$$

The assumption that the producing gas-oil ratio is the same at any time for each reservoir increment is in agreement with the use of the steady state flow at any time across the system. A tabulation of calculations in which this technique was used is given in Table III, the results are listed in Table II and are plotted in Fig. 8. This calculation gave a decline of reservoir pressure and variation of gas-oil ratio identical with that from the simpler approach, thereby indicating that an averaging of fluid characteristics was justifiable.

It might be noted that equation (5) can be used for any number of reservoirs producing simultaneously provided the producing gas-oil ratios of the separate reservoirs are equal and provided f_x represents the fraction of the total which each separate reservoir represents.

DECLINE OF PRODUCTIVITY INDICES

The data calculated in this analysis can also be used to indicate the relative decline in theoretical productivity indices. The rate of oil flow from the steady state system at any time is given by equation (2). The productivity index is equal to this rate of oil flow divided by the pressure differential of flow, or

$$\text{P.I.} = \frac{7.07\ kh}{(P_e-P_w)\ \ln\frac{r_e}{r_w}}\int_{P_w}^{P_e}\frac{k_o/k}{\mu_o\beta}\,dp \quad . \quad . \quad . \quad . \quad . \quad (6)$$

For unit permeability and thickness, the relative P.I. values between any two times will be given simply by the values of the integral divided by the respective values of (P_e-P_w) and $\ln\frac{r_e}{r_w}$. These ratios are plotted in Fig. 9. They show the effect of (P_e-P_w) and drainage radius on the P.I. decline. Each decline curve is for a constant drawdown and spacing value. Curves 1, 2, and 3 are for a constant drawdown of 1,000 psi and for r_e values of 300 feet, 750 feet, and 1,500 feet respectively. Curves 2 and 4 are for drawdown values of 1,000 psi and 200 psi respectively at a constant drainage radius of 750 feet. Since the history of a reservoir has been shown by preceding calculations to be independent of drainage radius and drawdown, the actual P.I. change in a reservoir due to change in operating drawdown or drainage radius could be found by interpolation on Fig. 9, after having established equilibrium values of reservoir pressure, gas-oil ratio, and cumulative withdrawal.

Calculation of the producing history of an internal gas drive reservoir with a definite drainage radius and pressure drawdown can be made by considering the reservoir to be a radial system flowing oil and gas under steady state. A succession of steady state calculations combined with the material balance concepts suffices to calculate withdrawals, gas-oil ratios, and pressure decline for the reservoir which possesses at any given time a pressure differential and a saturation differential from well radius to drainage radius. Although the method used involves several simplifying assumptions, the results are felt to be fairly representative of the internal gas drive reservoir.

It may be concluded from the calculations described that the history of an

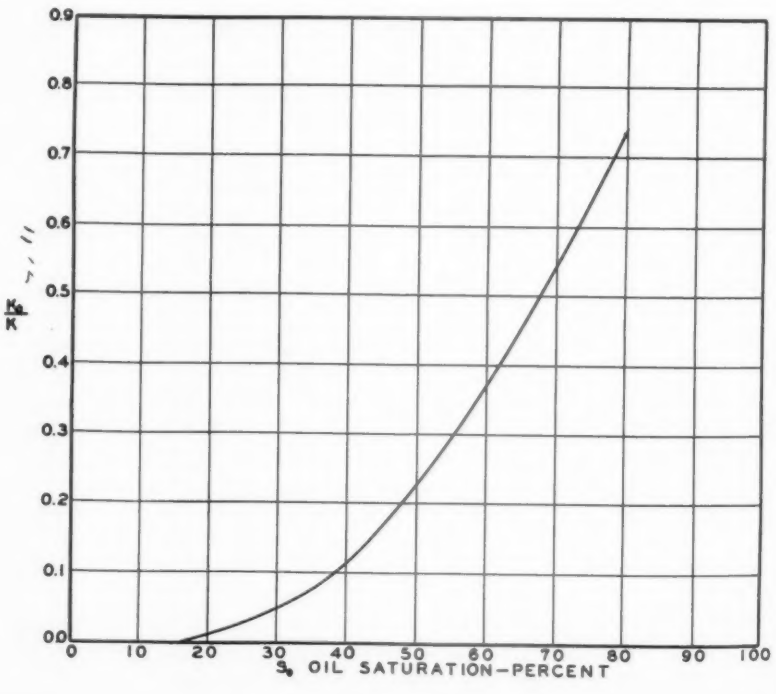

FIG. 6 — RELATIVE PERMEABILITY TO OIL

internal gas drive reservoir is independent of the spacing or pressure drawdown. In other words, from original pressure down to a given value of average reservoir pressure, one well will suffice to produce the same fraction of the total oil in place as will several wells. This conclusion does not consider possible economic limitations. From a standpoint of reservoir mechanics, the same result might have been anticipated from the generally accepted belief that the relative permeability to reservoir fluids is dependent only upon the fluid saturations.

It should be reiterated that in order to make such calculations as are reported here simplifying assumptions are necessary. The primary assumption has been that the reservoir is at any time flowing oil and gas under steady state conditions. In addition it has been assumed that the reservoir is homogenous, that water within the reservoir is uniformly distributed, that no water is produced, that gas and oil phases do not segregate by density differential within the reservoir, that there is no vertical flow within the reservoir, and that capillary forces can be neglected. Nevertheless, most of these assumptions apply to any analytical approach to reservoir behavior that can presently be made. The results of the present calculations are offered as a simplied approach to a difficult problem, and the results should be interpreted in that light.

The application of the predicted history of an internal gas drive reservoir as commonly made to practical operations would appear to be justifiable because the zero drawdown calculations give a result identical to that under all other assumed conditions. Further, the prediction of productivity indices on a theoretical basis to take into account presure drawdown would appear to be simplified.

The implications of the above analysis can be applied only to reservoirs where gas from solution is the sole producing mechanism.

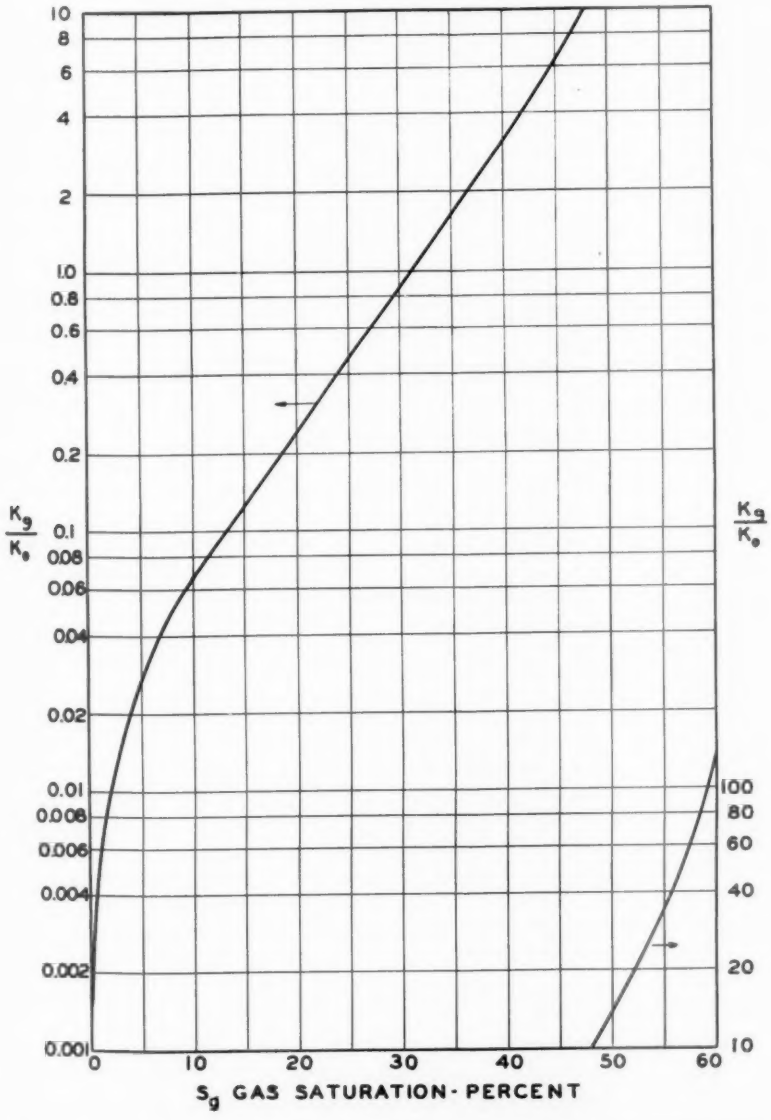

FIG. 7 — LOGARITHMIC RELATION BETWEEN RELATIVE PERMEABILITY RATIO AND RESERVOIR SATURATION

NOMENCLATURE

β = formation volume factor, barrels of reservoir oil per barrel of stock tank oil

μ_o = reservoir oil viscosity, centipoises

μ_g = reservoir gas viscosity, centipoises

N = original stock tank oil in place in reservoir system, bbl

P_e = pressure at drainage radius, psia

P_w = pressure at well radius, psia

P_x = pressure at radius r_x, psia

P_i = reservoir pressure at time i, psia

Q_o = rate of stock tank oil production, bbl per day

R = producing gas-oil ratio, standard cubic feet per barrel of stock tank oil

R_i = producing gas-oil ratio at time i

R_{i-1} = producing gas-oil ratio at time i-1

S_o = fractional reservoir oil saturation

S_g = fractional reservoir gas saturation

f_x = fraction of the total reservoir volume represented by the producing increment x

h = sand thickness, feet

k = permeability, darcies

k_g/k_o = relative permeability ratio, gas to oil

k_o/k = relative permeability to oil

ln = natural logarithm

n_i = stock tank oil produced up to time i, bbl

n_{i-1} = stock tank oil produced up to time i, bbl

n_{ix} = stock tank oil removed from producing increment x up to time i-1, bbl

r_e = drainage radius, feet

r_w = well radius, feet

r_x = any radius between r_e and r_w

s = gas in solution, SCF per stock tank bbl

s_o = value of s at original reservoir pressure

u = two-phase formation volume factor = $\beta + (s_o - s)v$

u_o = two-phase formation volume factor at original reservoir pressure

u_{ix} = two-phase formation volume factor at time i and increment x

v = gas conversion factor, bbl reservoir gas space per SCF

v_i = value of v at time i

v_{ix} = value of v at time i and increment x

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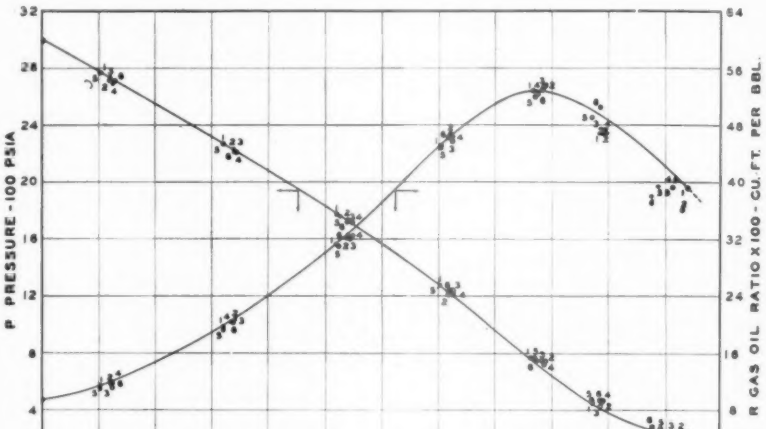

FIG. 8 — PREDICTED RELATIONSHIP BETWEEN PRESSURE AND CUMULATIVE PRODUCTION AND BETWEEN PRODUCING GAS-OIL RATIO AND CUMULATIVE PRODUCTION. NUMBERS REFER TO CALCULATIONS AS SHOWN IN TABLE II

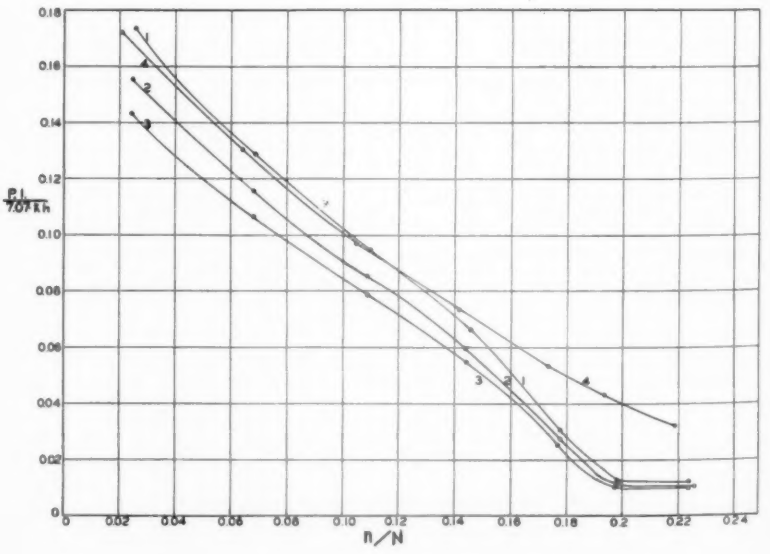

FIG. 9 — DECLINE OF PRODUCTIVITY INDEX FOR VARIOUS WELL SYSTEMS

A NEW COMPRESSIBILITY CORRELATION FOR NATURAL GASES AND ITS APPLICATION TO ESTIMATES OF GAS-IN-PLACE

E. B. ELFRINK, C. R. SANDBERG, AND T. A. POLLARD, MEMBER AIME
MAGNOLIA PETROLEUM COMPANY, FIELD RESEARCH LABORATORIES, DALLAS, TEXAS

ABSTRACT

This paper presents an evaluation of compressibility factor data and a discussion of their application to the estimation of gas reserves.

A correlation is presented which provides compressibility factors for use in both two-phase and single-phase hydrocarbon systems. Accuracies comparable to those obtained previously for single-phase systems only can be expected. A simple means of predicting the presence or absence of a liquid phase in a condensate system of known composition is illustrated.

The correlation is based on 1,030 compressibility determinations from 21 hydrocarbon samples taken from eight oil fields. Of the data used, 75 per cent were from California, 15 per cent were from the Mid-Continent area, and 10 per cent were from South America. The average numerical deviation of the experimental data from this compressibility chart is 1.22 per cent.

Charts and tables are included and discussed which illustrate the errors involved through the misuse or nonuse of compressibility factors in estimates of gas-in-place.

INTRODUCTION

The compressibility factor is a coefficient which expresses the deviation of a gas of given composition from the Perfect Gas Laws. A factor such as this is necessary in any calculation involving volumes of gaseous mixtures, and finds extensive application in the estimation of natural gas and condensate reserves. It is used in the decline curve, the volumetric, and the material balance methods of gas reserves estimation.

The behavior of gases at high pressures has been investigated extensively in recent years and considerable data have been assembled on the compressibility characteristics of a number of gases. Notable among the investigators of high pressure gas relationships are Kvalnes and Gaddy[6], Kay[5], Sage and Lacey[8], and Brown[3], Standing[14] and Katz[4]. Other contributors are Smith and Watson[12], Roland and Kaveler[7], and Stevens and Vance[15]. The data on compressibility factors assembled by these investigators have been presented and correlated in numerous ways; particularly noteworthy is the method first presented by Kay[5] which relates compressibility factor "Z" to pseudo-reduced temperature and pseudo-reduced pressure. Other investigators have used this empirical relationship successfully and numerous charts covering a large number of gases have been constructed on this basis.

It is the purpose of this paper to evaluate compressibility factor data and to illustrate the importance of their proper use in the estimation of gas-in-place for both gas and condensate reservoirs.

EVALUATION OF COMPRESSIBILITY FACTOR DATA

The compressibility chart presented by Standing, Katz, Brown and Holcomb[4] in 1941 is probably the most recent and reliable chart for natural gases. The reliability of the Katz chart has been investigated by the writers for a fairly large number of gases (single-phase) in the pressure range from 500 to 10,000 psia and temperature range from 80 to 400°F. A summary of this comparison is presented in Table I. The numerical average deviation of the chart compressibility factors from the experimental compressibility factors is 1.05 per cent, and the algebraic deviation is −0.28 per cent.

The Katz correlation appears to be quite accurate for single-phase hydrocarbon systems. It was based on single-phase systems and does not necessarily provide a means of accurately predicting the behavior of two-phase systems which might be encountered in condensate work. Data published recently by Sage and Olds[10] have enlarged the knowledge of phase behavior in condensate systems by covering extensively the compressibilities of systems in the two-phase as well as single-phase regions for a wide range of temperatures, pressures and gas-oil ratios. An evaluation of these data indicates that conditions can arise, especially in condensate systems having fairly low gas-oil ratios, in which two phases occur and the usual gaseous compressibility factors do not accurately apply.

The measured PVT data of Sage and Olds covering two-phase systems have been correlated with additional such data from the Mid-Continent[2] area and South America; these are presented in Fig. 1. This chart is the result of 1,030 compressibility* determinations from 21 hydrocarbon samples taken from eight oil and condensate fields. Of the data used, 74.75 per cent were from California, 15.45 per cent were from the Mid-Continent area, and 9.80 per cent were from South America. The chart construction is based on the original

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[1] References are given at end of paper.

* In this paper the term "compressibility" refers to the term "Z" in the equation PV = ZNRT, for either single- or two-phase systems.

compressibility correlation for natural gases developed by Katz et al[4]; it presents compressibility factors for both single-phase and two-phase systems (as determined by PVT measurements). Pseudo-reduced temperature and pressure and produced gas-oil ratio are required to use the chart. An evaluation of the accuracy of this compressibility chart is presented in Table II. The numerical average deviation of experimental data from chart values is 1.22 per cent, and the alegbraic deviation is -0.31 per cent.

It is necessary to be cautious in the application of any empirical correlation involving systems as complex as natural gases and condensates. The application of the correlation presented here should be restricted to systems similar to those used in the correlation until more extensive checks with other systems can be made. The properties of the hydrocarbon systems on which the correlation is based are presented in Table III. Also, this correlation does not cover pressures below 800 psia for systems having gas-oil ratios less than 10,000 cu. ft. per barrel.

APPLICATION OF COMPRESSIBILITY FACTORS IN THE ESTIMATION OF GAS RESERVES

As stated before, the compressibility factors of natural gas and condensate systems are used extensively in the decline curve, the volumetric, and the material balance methods of gas reserves estimation. The misuse or nonuse of compressibility factors in any of these methods results in sizeable errors of estimation. No attempt will be made here to cover the use of compressibility factors in all methods of reserves estimation; instead this paper will deal primarily with the volumetric method. Other authors[2] have covered in some measure the use of compressibility factors in the decline curve method.

The following is the general equation used to estimate gas-in-place by the volumetric method:

$$Q\dagger = \frac{43{,}560 \times \phi \times (1-S_w) \times 379.3 \times Z_i \times P \times E.R.}{Z_i\ RT}$$

Quite often in the use of the volumetric equation some of the terms and factors are not used or are overlooked. It has been the practice in some cases to use the compressibility of the produced gas at surface conditions and to neglect any correction for the liquid present. In the above equation, the equivalent ratio (E.R.) makes this correction. The gas-in-place can be overestimated by not using the equivalent ratio. This is illustrated in Fig. 2 for systems of various gas-oil ratios. This over-estimation can be as great as 15 per cent for systems of low gas-oil ratio (4,000-5,000 cu. ft. per barrel).

The errors resulting from the complete omission of the compressibility

TABLE I

Comparison of Calculated and Experimental Compressibility Factors (Katz Chart)

Gases Investigated	No. of Points of Comparison	Total Per Cent Error	Average Per Cent Error	Maximum Per Cent Error
Kettleman Hills gas by Sage and Lacy[9]	5	+ 3.28	+0.66	+ 1.0
	7	− 3.69	−0.53	−1.6
Rio Bravo gas by Sage and Reamer[11]	0			
	21	− 15.20	−0.72	−1.5
Eight gases in Phillips Laboratories[7]	66	+ 68.95	+1.04	+2.5
	72	− 56.84	−0.78	−2.5
Four gases in Texas A. & M. Laboratories[15]	24	+ 30.14	+1.26	+3.8
	45	− 99.04	−2.20	−6.7
Sixteen gases by Standing and Katz[14]	7	+ 9.95	+1.42	+4.2
	9	− 15.23	−1.69	−5.6
San Joaquin gas by Sage and Olds[10]	26	+ 7.92	+0.30	+0.6
	33	− 19.13	−0.58	−1.6
31 Gases total:				
Positive errors	128	+120.24	+0.94	
Negative errors	187	−209.13	−1.12	
Numerical average	315	329.37	1.05	
Algebraic average	315	− 88.89	−0.28	

TABLE II

Agreement of Experimental Data with Correlation (Fig. 1)

Gases Investigated	No. of Points of Comparison	Total Per Cent Error	Average Per Cent Error	Maximum Per Cent Error
San Joaquin Valley[10] (California)				
Wheatville Field (2 gases)	67	+ 52.67	+0.79	+2.03
	93	−102.33	−1.10	−2.67
North Belridge Field (4 gases)	76	+ 81.56	+1.07	+4.46
	149	−163.69	−1.10	−2.81
Helm Field (2 gases)	41	+ 31.05	+0.76	+2.02
	82	− 89.48	−1.09	−2.72
Paloma Field (5 gases)	108	+158.31	+1.47	+4.60
	154	−238.63	−1.55	−3.98
Mid-Continent				
Cayuga Field[2] (3 gases)	40	+ 48.29	+1.21	+3.95
	105	−169.91	−1.62	−3.01
Field B (2 gases)	14	+ 28.78	+2.06	+5.54
South America				
Field A (3 gases)	59	+ 68.86	+1.17	+5.05
	42	− 27.49	−0.65	−1.67
21 Gases total:				
Positive errors	405	+469.52	+1.16	
Negative errors	625	−791.53	−1.27	
Numerical average	1030	1261.05	1.22	
Algebraic average	1030	−322.01	−0.31	

† Nomenclature is given at the end of paper.

factor from the volumetric calculation can be quite large. As illustrated in Fig. 3, the per cent under-estimation of the gas-in-place becomes greater as the gas-oil ratio of the system is decreased and can be as large as 50 per cent in a 6,000 gas-oil ratio system existing as two phases at 3,000 feet. Errors as large as 20 per cent may exist for single-phase systems. The systems plotted in Fig. 3 in the gas-oil ratio range from 6,000 to 20,000 are partly liquid at some of the depths shown; nevertheless, accurate results can be obtained for these systems by using Fig. 1, if the total system composition is known. The curves presented here are primarily for illustrative purposes; and although the analyses of actual systems were used to calculate the data for the curves, it does not necessarily follow that all of the gas-oil ratio systems shown occur at all the depths shown.

The use of compressibility factors in the volumetric equation does not completely eliminate all sources of error. As mentioned earlier, the Katz compressibility factors for gaseous systems cannot always be applied to systems of low gas-oil ratio where conditions are such that a liquid phase is present at the temperature and pressure considered. Fig. 4 shows the per cent over-estimation of gas-in-place resulting from using gas (single-phase) compressibility factors for systems that are two-phase. Such errors would be minimized by using the chart presented in Fig. 1.

Fig. 1 has advantages over the normal single-phase compressibility charts in that it can be used safely in both single- (infinite gas-oil ratio) and two-phase regions. This chart can also be used with the Katz chart (included as part of Fig. 1) to indicate the presence of liquid in a system of known composition, at reservoir conditions. Any marked difference in compressibility factors from the two charts is a satisfactory indication of liquid being present in the system at the state point chosen. This is illustrated by examples given in Tables IV and V. It is believed that this usage of Fig. 1 will be of considerable value in indicating whether a condensate system is at or below dew point at reservoir conditions, in the absence of complete PVT data. In the actual determination of dew points by this method, the disagreement between the two compressibility factors will not necessarily be zero at the dew point, but will be within the accuracy of the

TABLE III
Properties of Systems Used in Correlation (Fig. 1)

System Number	Gravity Air=1	Mol Fraction Methane	Mol Fraction Heptanes+	Methane Plus Heptanes+	Mol Wt. Heptanes+
1	0.8611	0.8238	0.0292	0.8530	125.0
2	0.8181	0.8376	0.0228	0.8604	124.9
3	0.9603	0.7964	0.0973	0.8937	107.7*
4	0.7520	0.8642	0.0353	0.8995	107.7*
5	0.7089	0.8782	0.0225	0.9007	107.7*
6	0.6720	0.8903	0.0115	0.9018	107.7*
7	0.8441	0.8074	0.0237	0.8311	126.8
8	0.8310	0.8119	0.0217	0.8336	125.7
9	1.0170	0.7582	0.0576	0.8158	146.7
10	0.9585	0.7749	0.0476	0.8225	146.6
11	1.1160	0.7155	0.0919	0.8074	137.1
12	0.9955	0.7477	0.0659	0.8136	137.1
13	0.8267	0.7930	0.0295	0.8225	137.1
14	1.3812	0.6058	0.1265	0.7325	137.6
15	1.1750	0.6673	0.0882	0.7555	137.6
16	1.0520	0.7041	0.0653	0.7694	137.6
17	1.4745	0.6340	0.1449	0.7789	139.8
18	1.0700	0.7562	0.0749	0.8311	139.8
19	0.8201	0.8316	0.0317	0.8633	139.8
20	0.7317	0.8788	0.0225	0.9013	131.0
21	0.6996	0.8894	0.0143	0.9037	135.0

Typical Analysis

Component	Mol Fraction
Methane	0.8238
Ethane	0.0428
Propane	0.0351
Isobutane	0.0161
n-Butane	0.0303
Isopentane	0.0060
n-Pentane	0.0068
Isohexane	0.0034
n-Hexane	0.0065
Heptanes	0.0071
Octanes+	0.0221
	1.0000

*Hexanes+

TABLE IV
Comparison of Calculated and Measured Specific Volumes for a Condensate Mixture

Pressure, psia	pP_R	Z from Katz	Z from Figure 1	Per Cent Diff. in Compressibility	Specific Volume, cu. ft./lb. (Computed—Katz)	Specific Volume, cu. ft./lb. (Computed—Fig. 1)	Specific Volume, cu. ft./lb. (Measured)	Phase
5000	7.794	0.962	0.962	0.0	0.03760	0.03760	0.03748	Single-Phase
4500	7.015	0.892	0.892	0.0	0.03874	0.03874	0.03885	Single-Phase
3500	5.456	0.750	0.790	5.3	0.04188	0.04411	0.04395	Two-Phase
3000	4.676	0.686	0.747	8.9	0.04469	0.04866	0.04887	Two-Phase
2500	3.896	0.635	0.726	14.3	0.04964	0.05675	0.05696	Two-Phase
2000	3.118	0.599	0.724	20.9	0.05853	0.07074	0.07074	Two-Phase

$T=160°$ F.
$pT_R=1.273$
Gas-Oil Ratio=6241 cu. ft./bbl

two correlations. It has been found for a temperature of 150°F. this disagreement is 1.5 per cent at the dew point and for a temperature of 250°F. the disagreement is 0.5 per cent. The relationship between temperature and per cent disagreement is essentially linear between 150 and 250°F.

A sample calculation of gas-in-place for an actual condensate system, using Fig. 1, is presented in Table VI. Comparison of the result of this calculation with one using single-phase compressibility values shows that in the latter case a sizeable over-estimation of the gas-in-place would have resulted. Appropriate adjustments must, of course, be made in the final reserve estimates for effect of unrecoverable liquid phases left in the reservoir, for two-phase systems.

CONCLUSIONS

The present work demonstrates the feasibility of applying two-phase compressibility factors to two-phase systems for purposes of gas-in-place estimations, where representative composition data are available. Accuracies comparable to those obtained in single-phase systems using single-phase compressibility factors can be expected. A simple means of predicting the presence or absence of a liquid phase in a condensate reservoir is indicated, and the proper use of compressibility factors has been evaluated and illustrated.

ACKNOWLEDGMENTS

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TABLE VI

Example of Gas-in-Place Estimation Using Fig. 1 and the Katz Correlation

Given:

Reservoir Pressure, P = 2,500 psia
Reservoir Temp., T = 150°F.
Porosity, $\phi = 0.30$
Interstitial Water Content, $S_w = 0.23$
$_pP_R$ (Total Product at Reservoir Cond.) = 3.89
$_pT_R$ (Total Product at Reservoir Cond.) = 1.25
$_pP_R$ (Produced Gas at Std. Cond.) = 0.02179
$_pT_R$ (Produced Gas at Std. Cond.) = 1.259
Produced Gas-Oil Ratio = 6,241 cu ft/bbl
Trap Gas/Day = 2,754,000 cu ft
Vent Gas/Day = 223,116 cu ft
Tank Oil/Day = 477 bbl
Specific Vol of Tank Oil = 0.021314 cu ft/lb
Molecular Wt of Tank Oil = 120.06

A. *Using Fig. 1*

$$Q = \frac{43{,}560 \times \phi \times (1-S_w) \times 379.3 \times Z_1 \times P \times E.R.}{Z_2\ RT}$$

Z_1 from Fig. 1 = 0.996
Z_2 from Fig. 1 = 0.720

$$E.R. = \frac{2{,}977{,}116}{2{,}977{,}116 + \dfrac{(477 \times 5.615 \times 379.3)}{(0.021314 \times 120.06)}} = 0.8823$$

$$\therefore\ Q = \frac{43{,}560 \times 0.30 \times 0.77 \times 379.3 \times 0.996 \times 2{,}500 \times 0.8823}{0.720 \times 10.73 \times 609.6}$$

$$= 1{,}781{,}300 \text{ cu ft gas/acre-ft}$$

B. *Katz Chart*

Z_2 from Katz Chart = 0.623

$$\therefore\ Q = \frac{43{,}560 \times 0.30 \times 0.77 \times 379.3 \times 0.996 \times 2{,}500 \times 0.8823}{0.623 \times 10.73 \times 609.6}$$

$$= 2{,}057{,}475 \text{ cu ft gas/acre-ft}$$

$$\text{Per Cent Over-Estimation} = \frac{2{,}057{,}475 - 1{,}781{,}300}{1{,}781{,}300} \times 100 = 15.6$$

TABLE V

Comparison of Single-Phase and Two-Phase Compressibility Factors for Condensate Systems in Which Liquid Was Present at the State Point Chosen

Gas-Oil Ratio cu. ft./bbl.	Reservoir Pressure, psia	Reservoir Temperature, °F.	$_pT_R$	$_pP_R$	Single-Phase Compressibility Factor	Two-Phase Compressibility Factor	Per Cent Deviation	Phase
4000	2000	160	1.169	3.203	0.5200	0.6900	32.69	Two-Phase
6241	2500	150	1.250	3.890	0.6230	0.7200	15.56	Two-Phase
9260	3000	190	1.447	4.609	0.7600	0.8015	5.46	Two-Phase
24000	2600	130	1.330	3.950	0.6700	0.7150	6.72	Two-Phase
6241	4500	200	1.356	7.015	0.8990	0.8990	0.00	Single-Phase

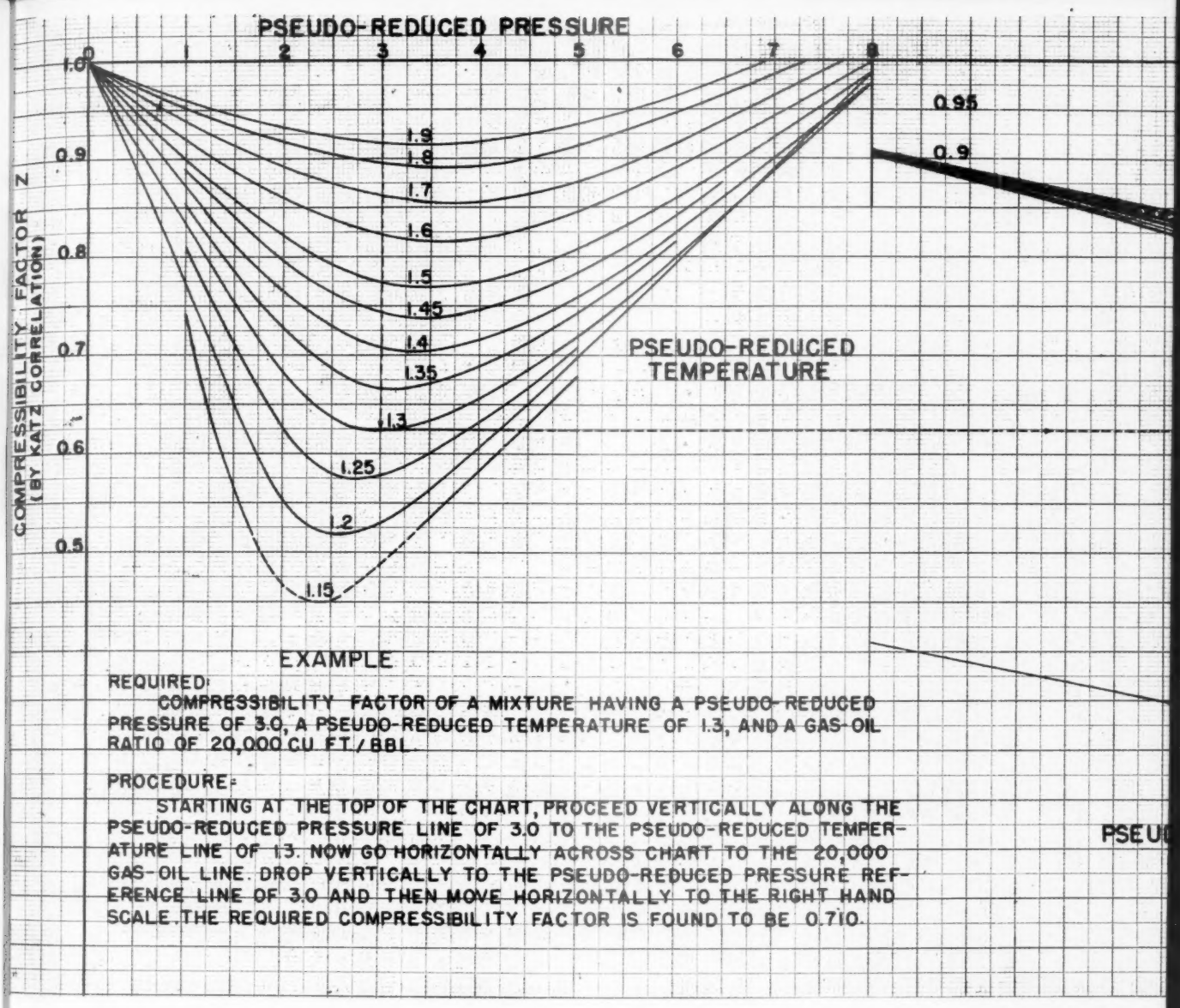


FIG. 1 — COMPRESSIBILITY
(BASED ON ORIGINA

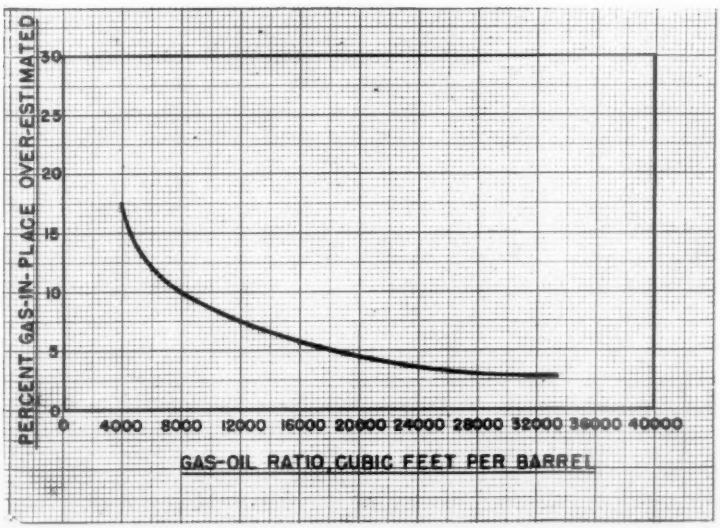


FIG. 2 — PER CENT ERROR RESULTING FROM OMISSION OF EQUIVALENT RATIO IN VOLUMETRIC EQUATION

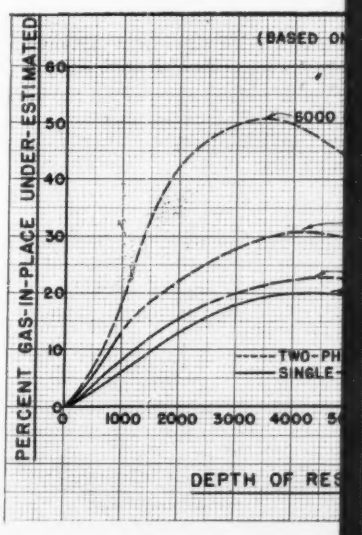


FIG. 3 — PER CENT ERROR RESULTING
FACTOR IN VOLU

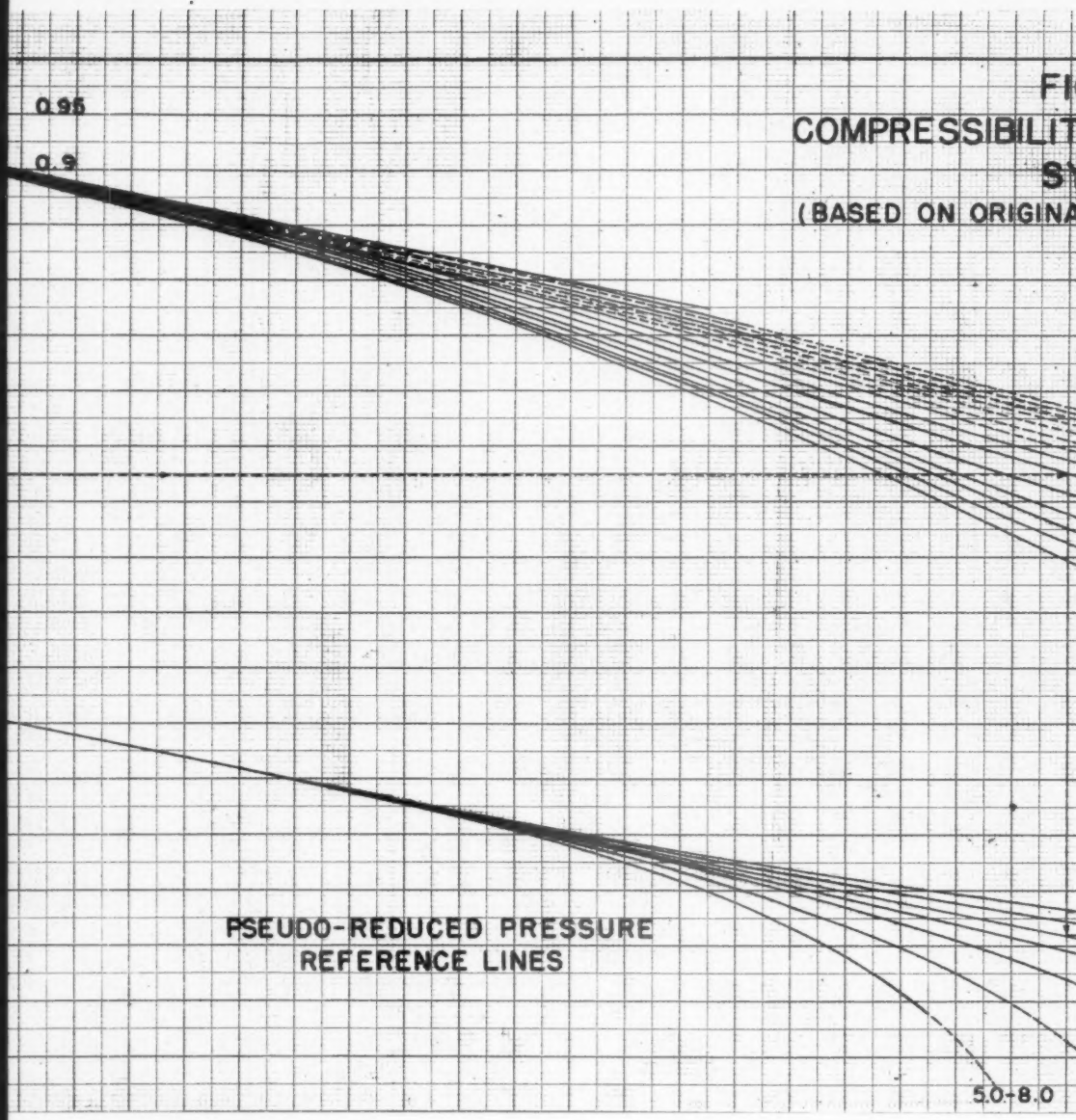


FIG. 1 — COMPRESSIBILITY OF HYDROCARBON SYSTEMS
(BASED ON ORIGINAL CHART BY D. L. KATZ)

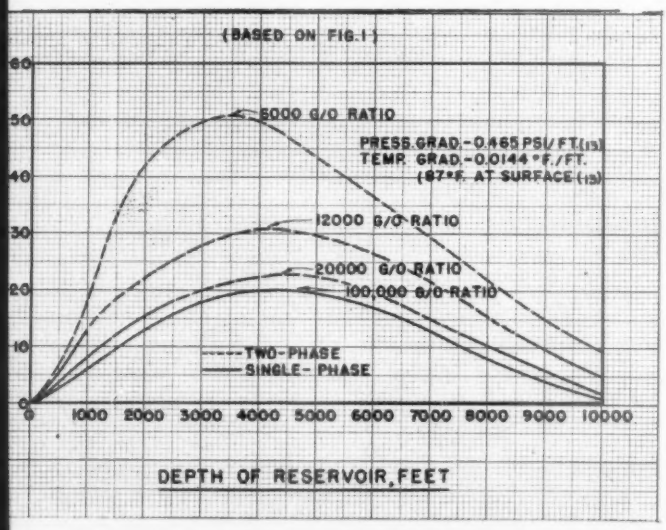


FIG. 3 — PER CENT ERROR RESULTING FROM OMISSION OF COMPRESSIBILITY FACTOR IN VOLUMETRIC EQUATION

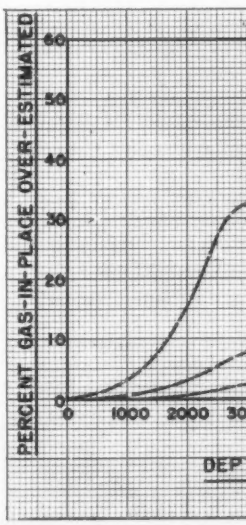
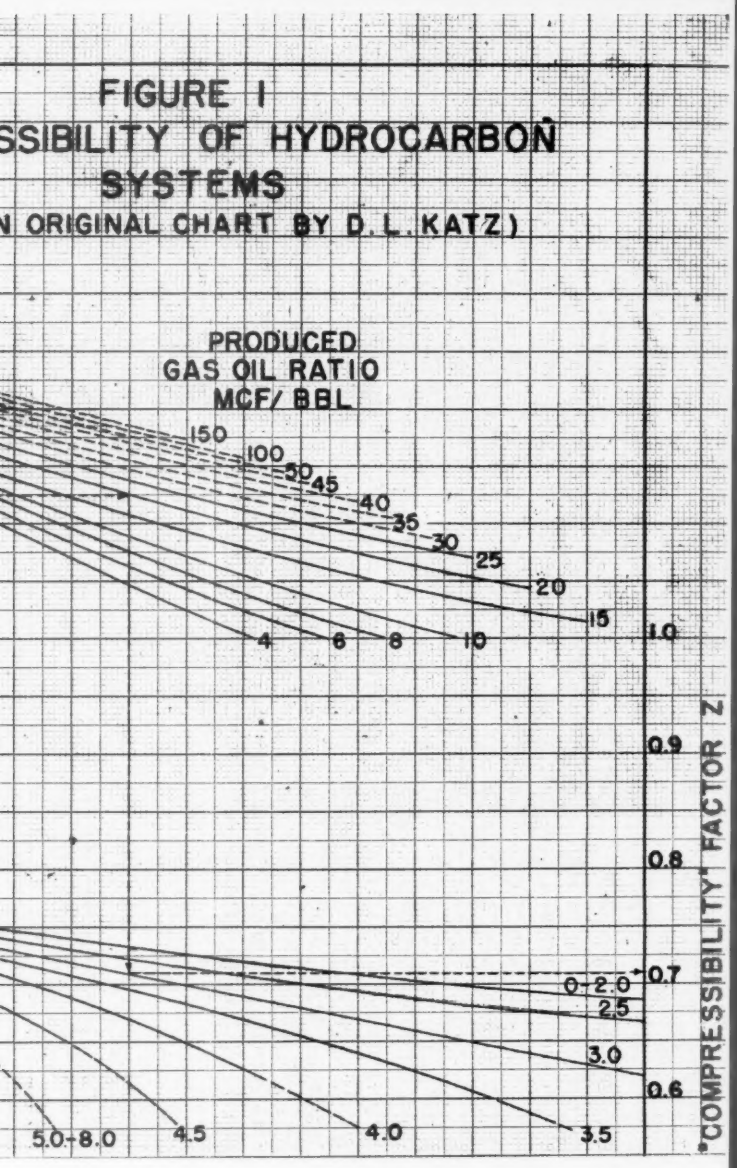


FIG. 4 — PER CENT
COMPRESSIBI

FIGURE 1

SSIBILITY OF HYDROCARBON SYSTEMS

N ORIGINAL CHART BY D. L. KATZ)



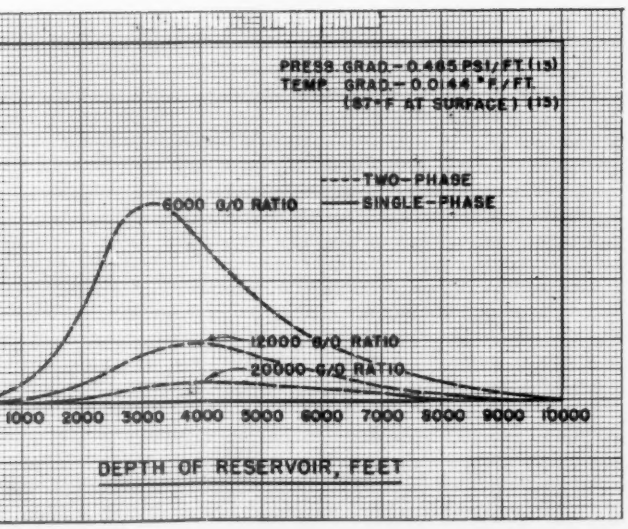

PRESS. GRAD. = 0.465 PSI/FT (13)
TEMP. GRAD. = 0.0144 °F./FT.
(67°F AT SURFACE) (13)
---- TWO-PHASE
—— SINGLE-PHASE
6000 G/O RATIO
12000 G/O RATIO
20000 G/O RATIO
1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
DEPTH OF RESERVOIR, FEET

FIG. 4 — PER CENT ERROR RESULTING FROM USE OF SINGLE-PHASE COMPRESSIBILITY FACTORS IN THE TWO-PHASE REGION

NOMENCLATURE

$$\left[\frac{\text{cu ft gas}}{\text{cu ft gas} + \left(\frac{\text{bbl oil x 5.615 x 379.3}}{\text{sp vol of oil x mol wt of oil}}\right)}\right] = \text{E.R. (equivalent ratio)}$$

P = reservoir pressure, psia

$_rP_R$ = pseudo-reduced pressure

$_rT_R$ = pseudo-reduced temperature

Q = cubic feet of gas-in-place per acre-foot at 60°F. and 14.7 psia

R = 10.73

S_w = interstitial water content of reservoir, expressed as a decimal fraction

T = reservoir temperature, °R (459.6 + °F)

Z_1 = compressibility factor of produced gas at 60°F. and 14.7 psia (can be determined from Fig. 1 by using left ordinate)

Z_2 = "compressibility" factor of entire system at reservoir conditions

ϕ = porosity, expressed as a decimal fraction

379.3 = volume in cubic feet occupied by one pound mol of gas at 60°F. and 14.7 psia

43,560 = number of cubic feet per acre-foot

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T.P. 2638

SOME EXAMPLES OF FLUID FLOW MECHANISM IN LIMESTONE RESERVOIRS

W. O. KELLER AND **R. A. MORSE,** JUNIOR MEMBERS AIME
STANOLIND OIL AND GAS COMPANY, TULSA, OKLAHOMA

ABSTRACT

The properties of limestone reservoir rocks such as the distribution and degree of continuity of the pore systems, and the relative volumes and permeabilities of the systems making up the complex cause large variations between performance of individual limestone reservoirs and their susceptibility to secondary recovery methods. The effects of these factors on the mechanism of fluid flow cannot be adequately evaluated with presently developed concepts, laboratory data, and geological information. The observance and interpretation of the performance of individual limestone reservoirs provides, at present, the most adequate approach for evaluating the integrated effects upon performance of the many, now immeasurable variations in the properties of limestone reservoirs.

INTRODUCTION

The development and application of techniques for increasing the efficiency of oil recovery from natural reservoirs is a problem of primary importance to the industry. During the past several years, a great deal of effort has been expended by the technical personnel of the industry toward the improvement of present known methods of oil recovery, and evaluating the factors which control the susceptibility of particular reservoir types to economic application of secondary recovery methods. Providing adequate and accurate laboratory data on the properties of the reservoir rock and its contained fluids, together with good production statistics, are available, methods have been evolved for estimating with reasonable accuracy the performance of an oil reservoir under either continued natural depletion or conditions imposed by introducing additional displacing fluid into the reservoir from an extraneous source through the injection of gas and/or water.

The susceptibility of limestone reservoirs to secondary recovery by gas injection is very much dependent upon gas-oil relative permeability relationships for the reservoir in question. In a rock formation in which the porosity is of the intergranular type such as is found in sand stones and some nonfractured dolomites, a representative sample of the pore structure can be obtained in a small core plug. In this type of reservoir, it has been shown that relative permeability data obtained from laboratory experiments can be properly applied to evaluate the flow relationships actually observed during the depletion of a reservoir. In addition, a good idea of the fraction of the reservoir which will be swept by the injected gas may be obtained from the spacing pattern used and the permeability profile of cored wells. From these data, it has been demonstrated that reliable estimates of performance and recoveries under gas injection operations can be made for reservoirs in which the porosity is of the intergranular type.

Limestone reservoirs on the other hand often present much more complex problems. One reason that the performance of limestone reservoirs is so variable is that there may be, in reality, two or more pore systems, the integrated performance of which will depend upon the physical properties of each system and their inter-relationship. For instance, in a limestone reservoir, the main pore structure, as far as void spaces for storage of hydrocarbons is concerned, may be represented by the intergranular openings of the rock. Usually in limes and dolomites, the intergranular pore openings are very small and the matrix permeabilities extremely low. Often, as in the case of many dolomite and oolitic lime reservoirs, this is the only pore system, and performance is observed to be very similar to that of a sand stone of similar permeability. However, in the great majority of the limestone reservoirs, there is present, in addition to the intergranular pore system, a complementary system of openings caused by fracturing or solution.[1,2] The openings in the latter system are usually many times more permeable than the intergranular pore system due to their much larger size, and may contribute almost all the fluid carrying capacity of the formation, even though their volume may be a very small part of the total pore space in the reservoir. Obviously, the performance of such a complex under either primary or secondary control will depend upon the distribution and degree of continuity of both systems, the relative volumes and permeabilities of the

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[1] References are given at end of paper.

two systems; and in some instances, the rate of fluid withdrawals from the reservoir. For instance, if the volume of a *highly interconnected* secondary pore system is relatively small and of much higher permeability, compared to the intergranular system, the properties of the secondary pore system will exercise considerable control over performance. On the other hand, if the intermediate porosity is dispersed such that interconnection is largely through the matrix pore system, then the extent to which performance will be governed by properties of the secondary system will be minimized.

The infinite variety of possible combinations of continuity, relative volumes and permeabilities of intergranular and secondary pore spaces makes the study of performance of limestone reservoirs an enormously complex problem. Obviously, laboratory relative permeability relationships determined on matrix of the reservoir rock cannot be depended upon, at least under all conditions of production that might be encountered. Usually, due to the size and distribution of the openings in the secondary system of porosity, it is impossible to obtain a representative sample of the reservoir rock with a reasonably sized core. Hence, laboratory data cannot be relied upon completely, at least at the present stage of development, to provide relative permeability data which can be applied directly to limestone reservoir performance problems. For this reason, it has been found desirable to calculate, from field performance data, the relative permeability relationships for a particular field and to extrapolate these data to evaluate future performance either under primary or gas injection operations. Even this method is open to the objection that the relationships obtained at one condition of production rate and rate of pressure decline may not be strictly applicable to another set of conditions. For this reason, with our present knowledge, it is impossible to set up as rigid a depletion program for such limestone reservoirs. The best approach that can be made at present is to use field performance data as an indication of the behavior to be expected under secondary recovery operations, and set up a program on the basis of such indications, followed by constant engineering surveillance of the project, making such changes as are dictated by performance of the field and experience on similar projects.

Obviously, such gas injection projects must be experimental and exploratory in nature, with the better engineering of future projects being based on close study of good data on similar projects in like reservoirs. Following are brief reviews of performance data from a number of limestone reservoirs. It is believed that the study of these and other limestone reservoirs will enable the development of increasingly better engineering analyses of secondary recovery possibilities by gas injection, as well as increase the general fund of knowledge on the complex problem of the displacement processes in limestone reservoirs.

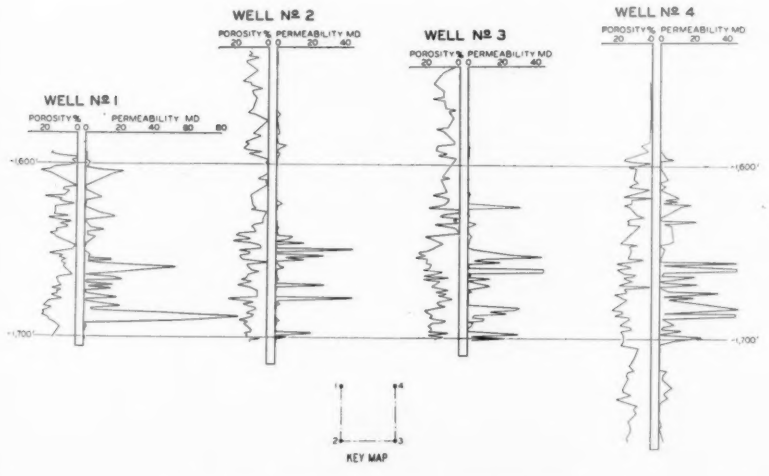

FIG. 1 — FIELD "A", CORE GRAPH CROSS SECTION

FIELD "A"

Field "A" is a volumetrically controlled, relatively tight, dolomitic limestone reservoir.

Production is obtained from the San Andres formation, of Permian age, encountered at an average depth of approximately 4,750 feet. Seventy producing wells, located in the center of 40-acre units have been drilled to date within the presently developed area consisting of approximately 3,000 acres. Some development is still under way.

Although the oil accumulation is located on a structural high with approximately 100 feet of closure, the productive limits of the field are apparently controlled primarily by lack of porosity and permeability development rather than structural conditions. A definite water level has not been established, although there is some evidence that indicates that the water saturated porosity underlying the oil reservoir is not a level surface but tends to follow the structure.

The producing zone, consisting predominantly of gray crystalline dolomite, has a gross thickness of approximately 200 feet; however, based on core analysis from 14 wells in the field, the pay zone, consisting of erratically distributed streaks of permeable, porous rock, amounts to only ten to fifty per cent of the gross section. The vertical permeability distribution is illustrated by the core graphs shown in Fig. 1. As can be seen from the key map on Fig. 1, the four wells represented are all mutually direct or diagonal offsets, so that the variation shown exists at the four corners of a 40-acre area represented by the location of the wells. The permeability profile is highly irregular in any particular well, which might indicate poor sweeping of the formation by an injected medium, due to by-passing in the more highly permeable zones. It can be noted from Fig. 1 that the individual stringers of high and low permeability do not appear to be continuous between wells. This suggests the possibility that the producing for-

mation is made up of areally irregular zones of varying permeability and size, interfingered so that the effects of vertical variations in permeability, indicated in individual core analysis are greatly minimized to the extent that the flow of injected gas through the formation would be fairly evenly distributed throughout the productive zone. The probability that the areal distribution of the more permeable portions of the pay may be interfingered and erratic, as is the vertical distribution, has been borne out by the performance of the gas injection program initiated in April, 1946, as will be illustrated.

The wells are characterized by very low productivities, with initial productivity indices, after shooting, ranging from .05 to .5 barrels per day per pound pressure drop. The average productivity index is in the neighborhood of .2 barrels per day per psi. All the wells were completed as pumping wells, or were put on the pump very soon after completion. Completion practices in the field have consisted of setting casing at the top of the pay and shooting with solid nitroglycerin. A few wells have been acidized; however, acidization to stimulate productivity has been unsuccessful.

Based on several bottom hole sample analyses, the reservoir oil which was undersaturated at the initial reservoir pressure of 1,954 psig (−1,500 feet datum), has the following characteristics:

1. Bubble point pressure at reservoir temperature of 94°F. = 326 psia
2. Solubility (by differential vaporization) = 140 cu ft/bbl
3. Reservoir volume factor of bubble point oil = 1.091.
4. Viscosity at 326 psia and 94°F. = 2.25 cp
5. H_2S content of solution gas 1.776 grains/100 cu ft

As shown by Fig. 3, the average producing gas-oil ratio has been approximately equal to the solution ratio.

Because of the undersaturated nature of the reservoir oil, the expulsive force causing oil production during the period preceding gas injection was furnished entirely by the expansion of the liquid oil in the reservoir. It was apparent early in the development of the field that, due to the undersaturated condition, a very rapid drop in reservoir pressure would occur down to the bubble point pressure, resulting in a rapid drop in the productivity of the wells, due primarily to the reduction in the available pressure differential. It was also apparent that, under natural depletion, the productivities of the wells would be further drastically reduced at such time as the reservoir pressure declined below the bubble point since, at this time, the presence of liberated solution gas would materially reduce the effective permeability to oil and, at the same time, there would be very little pressure differential to accomplish flow. This reservoir pressure and well productivity performance is depicted graphically by Figs. 2 and 3.

Based on these factors, it was estimated that a small percentage of the oil could be produced at economic rates by internal gas expansion. Engineering estimates indicated that the abandonment of the reservoir under natural depletion would have been necessary when the reservoir liquid-saturation was still in excess of 90 per cent, with approximately 20 per cent of the expected ultimate recovery being attributed to liquid expansion above the bubble point pressure. Although it was not possible to calculate precisely what the expected effect of this performance would be upon the oil production rate from the field since complete data on relative permeabilities were not available, an approximation of the rates to be expected is shown by the extrapolated curve of expected oil rates on Fig. 2. Those estimated rates under primary production were calculated using a typical relative permeability to oil curve from laboratory data and an average initial P.I. of .2 bbls. per day per psi.

Although very little primary performance data, upon which to base studies of the anticipated performance under secondary recovery methods could be obtained prior to the time such methods were necessary, the high abandonment liquid saturation anticipated under primary operations made almost mandatory the early injection of gas or water. It was realized that such opera-

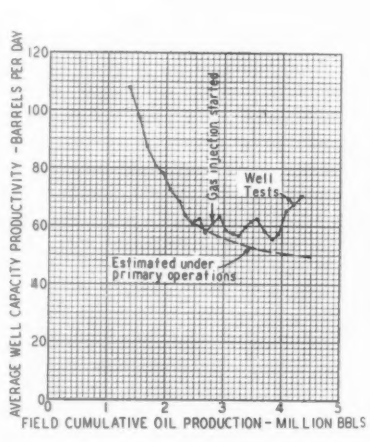
AVERAGE WELL CAPACITY PRODUCTIVITY - BARRELS PER DAY
FIELD CUMULATIVE OIL PRODUCTION - MILLION BBLS
Gas injection started
Well Tests
Estimated under primary operations

FIG. 2 — FIELD "A", AVERAGE WELL PRODUCTIVITY VS. CUMULATIVE PRODUCTION

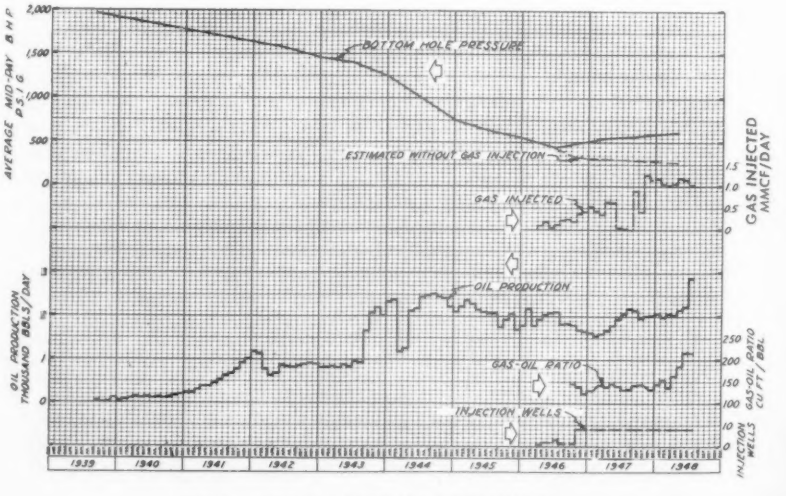

FIG. 3 — FIELD "A", RESERVOIR PERFORMANCE

tions would entail considerable risk, in view of the many unknown reservoir factors involved, probably the most important of which was the areal extent and continuity of the more permeable streaks, which would control the amount of by-passing of the injected medium to be expected. It was felt, however, that the possible gains to be derived from depletion of the reservoir by secondary methods more than outweighed the risk involved. Moreover, it was believed that the information derived from this project would be of considerable benefit in planning the depletion programs for similar limestone reservoirs encountered in West Texas. After study of all the available data, the decision was made to install an experimental gas injection program in the field to maintain the reservoir pressure at a level somewhat in excess of the bubble point of the reservoir oil, in order to provide an adequate pressure differential to produce oil at economic rates, supplement the available displacing fluid, and improve the recovery efficiency by maintaining more favorable saturation conditions within the reservoir.

For the purpose of conducting the injectivity tests, and also to provide injection facilities until a permanent plant could be constructed, a portable compressor was moved into the field and gas injection started in April, 1946, as shown by the performance curves in Fig. 3. Injection tests were made on all the contemplated injection wells, and fairly continuous gas injection into one well was accomplished by the use of the portable compressor. The injection tests indicated that gas could be injected in sufficient volumes to maintain reservoir pressures by the use of an injection pressure of approximately 1,000 psi. Fluid level depression tests, made in conjunction with the injection tests, indicated that the gas was being forced fairly uniformly into the entire formation.

In September, 1947, the permanent compressor station was put into operation, along with the electrical generating station to furnish power to operate the pumping wells. Gas has been injected into seven injection wells almost continuously since that time. Gas is currently being injected into eight wells on a nine-spot pattern at rates adjusted to replace all withdrawals from the surrounding wells and, at the time time, eliminate large pressure differentials across the field.

Bottom hole pressure, oil production rate, gas injection rate, and gas-oil ratio performance of the field are illustrated on Fig. 3. The bottom hole pressure had declined to slightly less than

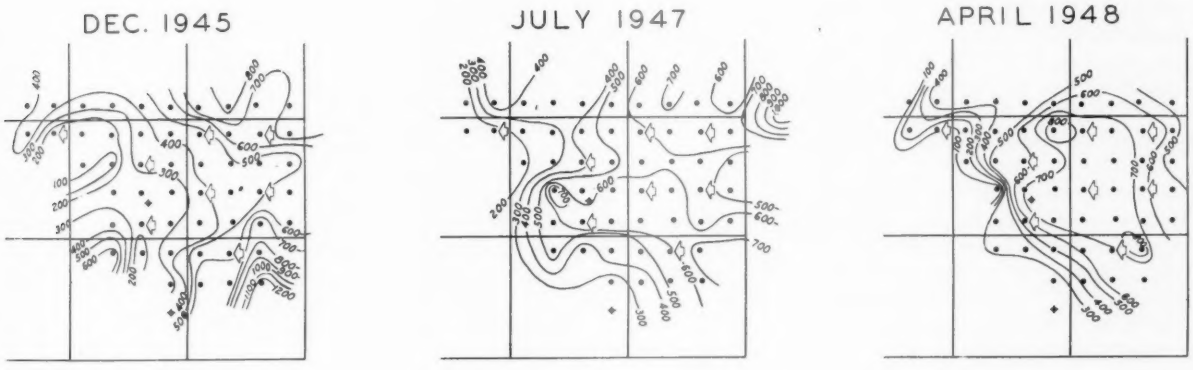

FIG. 4A — FIELD "A" RESERVOIR PRESSURE MAPS

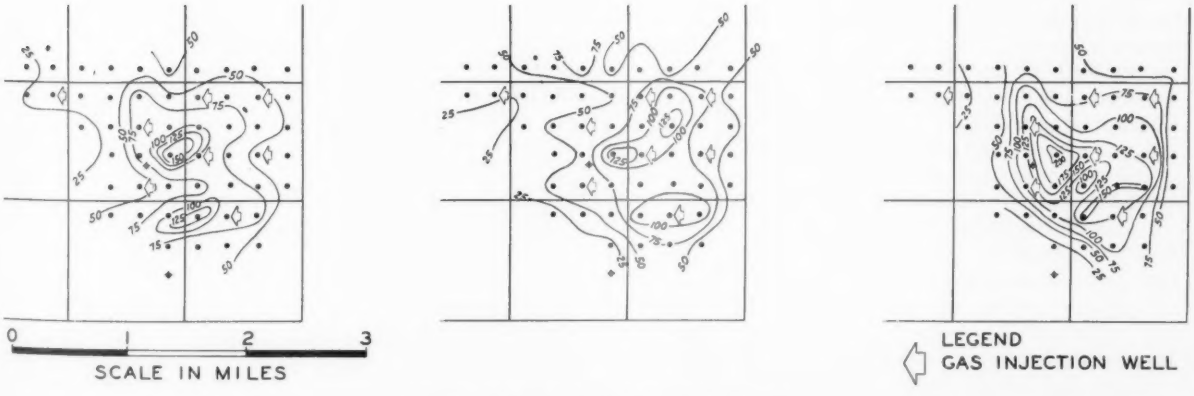

FIG. 4B — FIELD "A" WELL PRODUCTIVITY MAPS

400 pounds prior to gas injection, and since the start of gas injection operations, the pressure has been gradually increased and maintained at slightly in excess of 500 psig. The effect of the gas injection program upon the pressure performance of the field and upon the producing capacities of the wells is illustrated by Fig. 4 which shows the pressure distribution and the well productivity distribution in the gas injection area immediately preceding the start of the gas injection program, 16 months following the start of injection, and at the present time, after 2½ years of injection operations.

It will be noted, from Fig. 4, that productivity decline has been arrested and, in most of the area, substantial increases in productivities have been experienced. At the same time, individual well productivities are considerably more uniform than they were prior to gas injection. As a result of the improved performance characteristics, the producing rate for the field has been increased from 2,037 bbl/day before gas injection to approximately 3,000 bbl/day at present. It will be noted from Fig. 4 that, in general, the reservoir pressure has been increased, the pressure differentials throughout the field minimized, and that this change in pressure distribution has resulted in a corresponding change in distribution and magnitude of the producing ability of the wells. The effect of the program upon the producing capacity of the wells is further illustrated by the curve shown on Fig. 2, which shows the average well capacity based on production tests, both before and after the start of gas injection.

In connection with the gas injection program in the field, an attempt is being made to record the engineering information in enough detail to allow very close study of the results. Individual well productivity and gas-oil ratio tests are made at intervals of two months, and all gas produced is metered by individual tank batteries, each of which handle the production from three or four wells. Individual well gas-oil ratio tests taken bi-monthly since the start of gas injection operations show that no changes in the gas-oil ratios resulted from gas injection until March, 1948, at which time an increase in gas-oil ratio from approximately 150 cubic feet to 400-800 cubic feet was noted on three wells offsetting the same injection well. With the exception of these three wells in the field, all of the wells are still producing at approximately the solution ratio. An analysis of this area, where the injection gas has apparently broken through to the producing wells indicates that the gas injection volumes are equivalent to an average gas saturation of approximately 4.1 per cent assuming that the gas is uniformly distributed throughout the vertical pay section, and 28.1 per cent assuming that the gas entered only the portion of the reservoir indicated by core analysis to have a permeability in excess of 5 millidarcys.

In planning this program, it was recognized that no appreciable benefits could be expected if the injected gas confined itself to the more permeable channels of flow within the reservoir and did not disseminate gas through the denser, less permeable portions of the reservoir which, based upon core analysis data, probably contained from 60 per cent to 70 per cent of the initial oil in place. There is considerable weight of opinion among engineers which contends that gas injection in a limestone reservoir such as Field "A" cannot be successful for the reason that the injected gas would selectively flow through only the more permeable channels and, therefore, could not be effective in displacing oil in the denser, less permeable portions of the reservoir which contain the majority of the oil in place. In order to arrive at tentative conclusions in this respect, the gas saturation in the area surrounding each input well has been calculated, utilizing two extreme assumptions. It was first assumed that all the injected gas entered into only the zones having a permeability in excess of 5 millidarcys. The gas saturation was then calculated utilizing the other extreme assumption, that is, that the injected gas displaced oil uniformly throughout the entire permeable zone, irrespective of the magnitude of the permeability. The results of these calculations are shown by the following table:

Injection Well	Calculated Gas Saturation in 160-Acre Area: Net Pay Above .05 Md	Net Pay Above 5 Md	% of Net Pay With Permeability in Excess of 5 Md
1	4.1	28.1	14.6
2	3.0	8.1	36.6
3	4.8	22.0	21.9
4	4.5	11.3	40.1
5	2.4	9.3	26.1
6	1.9	6.2	31.1
7	2.8	7.6	36.3
Weighted Average	3.4	11.3	32.0

As can be seen from the above table, it is indicated that, if the injected gas had displaced oil only in the more permeable zones, gas saturations ranging from 6.2 to 28.1 per cent would exist in these zones. Either of these gas saturations are believed to be considerably in excess of the equilibrium gas saturation and, if this had occurred, gas

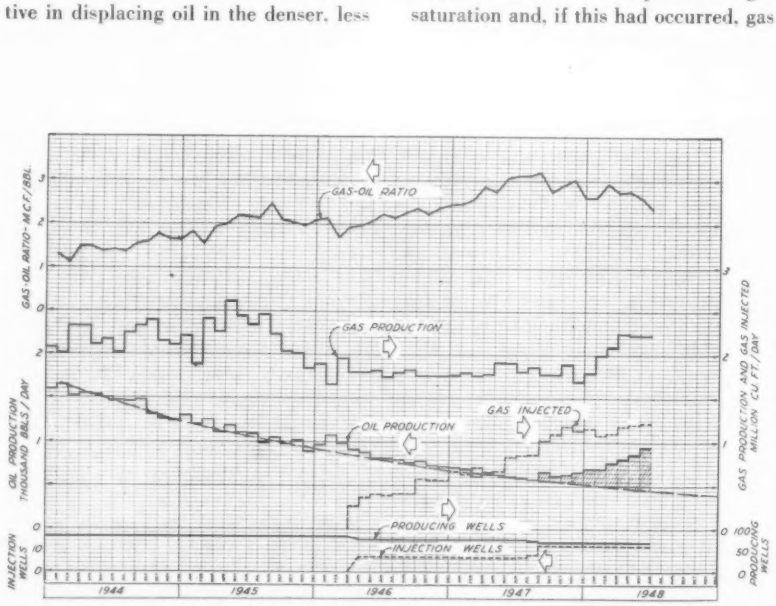

FIG. 5 — FIELD "B" TYPICAL GAS INJECTION PERFORMANCE

should have broken through to the offsetting producing wells, which would experience very rapid increases in gas-oil ratios. This has not been the case. On the assumption that all of the gas entered into the entire permeable pay section, the above table shows that a gas saturation of from 1.9 to 4.8 per cent would exist. These gas saturation values are of the order of magnitude of the equilibrium gas saturation to be expected, so it is anticipated that the producing wells will soon experience increasing gas-oil ratios. The time required before this occurs, and the subsequent increases in the gas-oil ratio of producing wells should provide a basis for an approximate quantitative estimate of the equilibrium gas saturation and some idea of the gas saturation distribution.

Although the project has not been in operation for sufficient length of time to arrive at definite conclusions as to the sweep efficiency of the injected gas and the ultimate benefits to be expected from the program, the following tentative conclusions are drawn: (1) The injected gas has not channeled to producing wells by selectively entering the more permeable portions of the reservoir to the exclusion of the less permeable portions. To the contrary, it appears that the more permeable sections of the reservoir are so interfingered, and the areal distribution of the permeable streaks sufficiently erratic to allow the injected gas to displace oil out of a large per cent of the reservoir rock. This tentative conclusion does not mean that channeling of injected gas will not occur. In a dispersed gas injection program, it necessarily follows that the injected gas must be produced sooner or later; otherwise, the displacement efficiency of the injected gas would be 100 per cent. Prior to the time gas break-through occurs in the producing wells, the displacement efficiency of the injected gas, in terms of pore volumes of oil displaced per pore volume of gas injected, is 100 per cent since all the gas injected has displaced oil. Once gas breaks through to the producing wells the producing gas-oil ratio can be expected to increase at a rate which will be governed by the nature and distribution of the permeable portions of the reservoir, the gas saturation gradients developed, and by relative permeability relations. After break-through, the displacement efficiency of the injected gas will probably decrease very rapidly; however, it is expected that a large increase in recoverable oil can be obtained in this field prior to the time it becomes no longer economical to inject gas due to high producing gas-oil ratios. (2) The reservoir pressure has been maintained above the bubble point and pressure gradients throughout the gas injection area minimized, thus preventing the rapid decline in producing capacity of the wells which would undoubtedly have occurred if the reservoir pressure had been allowed to decline below the bubble point. (3) The rapid decline in producing capacity of the wells in the gas injection area observed prior to the gas injection program has not only been halted, but the producing capacity has been very materially improved.

FIELD "B"

Field "B" is a volumetrically controlled, North Texas, dolomitic limestone field, which has been operated under a fieldwide dispersed type gas injection program for the past 2¼ years.

Structurally the field is a broad, plunging anticlinal nose, cut by a steeply dipping anticlinal fold or fault roughly parallel to the main axis of the anticline. The productive limits of the field are defined by the oil-water and gas-oil contacts which are irregular surfaces and, also the variation in porosity and permeability development. In general, a concentration of non-porous zones exists above the oil pay and below the gas saturated porosity. This same general condition exists at the base of the oil saturation above the water-oil contact. Very restricted communication exists between the oil reservoir and the overlying gas zone in minor localized areas. The primary depletion performance has essentially been by internal or solution gas drive.

Unfortunately, lack of core data makes difficult a very satisfactory understanding of the characteristics of the reservoir rock as to the nature, magnitude, and distribution of the porosity and permeability development. The gross pay interval is composed of four major stratigraphic zones which are fairly persistent. The lithology of the gross pay zone is very heterogeneous and varies over a wide range from cherty granular dolomite to white crystalline dolomite, and from oolitic limestone containing varying amounts of secondary cementing material to arkosic limestone intermingled with green shale. From microscopic examination of bit cuttings, it is observed that the character of the porosity ranges from fine grained crystalline type porosity to pore openings containing numerous vugular scattered pores. Although a quantitative estimate of the relative volumes of the reservoir represented by different types of porosity is not possible, it appears that the nature and magnitude of both the permeability and porosity represented vary over an extremely wide range.

The field was produced under primary control throughout its depletion history prior to gas injection, and had recovered approximately 85 to 90 per cent of the expected primary oil reserves at the time the gas injection program was initiated. The field had been producing at substantially capacity rates for several years prior to gas injection. At the time gas injection operations were started, the average well was producing at capacity of 13 barrels per day with a gas-oil ratio in the neighborhood of 1,350 cubic feet per barrel. This ratio is 8 to 10 times the solution ratio at the existing reservoir pressure of about 250 psi, thus indicating that, prior to gas injection, appreciable gas saturation and permeability to gas had been developed within the reservoir.

Typical performance data, based on several properties in the gas injection area, are illustrated by Fig. 5 for a 2¼ year period before and an equal period after commencement of gas injection. Two outstanding results of the gas injection program are obvious from Fig. 5: (1) The apparent gas-oil ratio trend observed during the period prior to gas injection has remained substantially unchanged during the life of the gas injection program to date. (2) Oil production capacities have been leveled out and increased to approximately the same magnitude as of the time gas injection operations were started.

It should be pointed out that some of the improvement in production rate is attributable to workovers (cleanouts

and acidizations) which were performed on some of the wells after gas injection was commenced. However, comparisons of well performance following workovers before and after the start of gas injection indicate that most of the sustained increases in production rate can be credited to the gas injection program.

Unfortunately, reservoir pressure data is inadequate to enable the interpretation of these results in terms of the magnitude of the oil and gas saturation and relative permeability values; however, it is obvious from the gas-oil ratio curve on Fig. 5 that the apparent permeability to gas has not been materially increased as a result of the gas injection program. Adopting the interpretation that there has been no change in the gas-oil ratio as a result of gas injection, the injected gas volume to date, which is approximately equivalent to 6.8 million barrels of reservoir space, must have displaced oil and accomplished a redistribution of oil saturation such that no increase in the apparent relative permeability ratio (Kg/Ko) resulted. The external gas drive displacement efficiency (reservoir volume of oil displaced per reservoir volume of gas injected) is thus indicated to be approximately equal to the displacement efficiency by internal gas drive during the injection period to date.

Adopting the other extreme interpretation of the effects of gas injection on the gas-oil ratio trend it might be interpreted that the gas-oil ratio curve during the injection period would have levelled out at approximately 2,000 cubic feet per barrel under primary operations. On this basis, it is calculated that the excess gas production represented by the increase in gas-oil ratios during the gas injection period is 52 per cent of the total injected gas volume. Even under this extreme interpretation, it is obvious that the injected gas must have displaced oil rather efficiently and adjusted the saturation distribution so that the displacement efficiency by external gas drive to date is approximately equal to one-half the displacement efficiency of solution gas drive.

Following is a tabulation of the pertinent production statistics from these leases for the 2¼ year periods preceding and following start of gas injection:

	2¼ Years Before	2¼ Years After
Oil Production	1,020,000 bbl	625,000 bbl
Gas Production	1,780,000 Mcf	1,533,000 Mcf
Gas Injection	0	655,300 Mcf
Net Gas Production	1,780,000 Mcf	877,700 Mcf
Gross gas-oil ratio	1,745 cu ft/bbl	2,450 cu ft/bbl
Net gas-oil ratio	1,745 cu ft/bbl	1,405 cu ft/bbl

Since the ultimate oil recovery from a volumetric field is a function of the efficiency of utilization of the available gas volumes to displace oil, the relative recovery efficiency can be qualitatively evaluated by a comparison of net gas-oil ratios. As can be seen from the above table, the net gas-oil ratio during injection is 20 per cent less than the net gas-oil ratio prior to gas injection, and from 43 to 30 per cent less than the maximum and minimum gas-oil ratios that could have been predicted under primary operations during the gas injection period. The fact that the net gas-oil ratio has been materially improved certainly indicates that the increase in producing rate, above normal decline, shown by the shaded area on Fig. 5 represents, to some extent, an increase in ultimate recovery as well as an increase in recovery rate.

For the gas injection program to have been ineffectual in improving ultimate oil recoveries, the increase in produced gas volumes attributable to gas injection should have approached the same magnitude as the injected volumes; however, the most pessimistic interpretation indicates that the increase in gas production due to gas injection to date has been approximately 50 per cent of the injected gas.

FIELD "C"

Field "C" is located in West Texas and produces from cavernous porosity of the El Capitan reef limestone of Permian Age at an average depth of 2,900 feet. The field was drilled on a spacing of approximately 10 acres per well. Wells in the field were characterized by very high initial productivities ranging up to 20,000 barrels per day. For the past 10 years, wells have been in the stripper status due to the high volumes of water produced with the oil.

Even at the very high rates of production experienced in the early life of the field, it is doubtful if the reservoir pressure was, at any time, reduced enough to cause significant volumes of solution gas to be liberated from the reservoir oil. The extremely active water drive has maintained the reservoir pressure to the extent that the present pres-

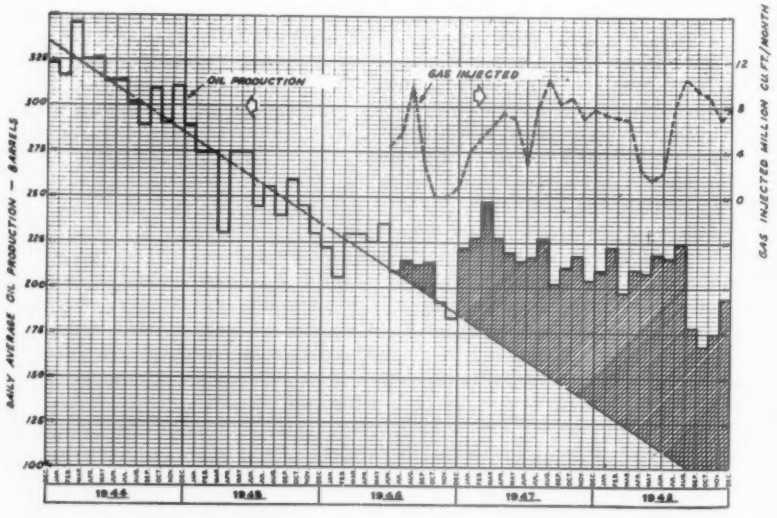

FIG. 6 — FIELD "C" GAS INJECTION AND DAILY OIL PRODUCTON RATE, EXPERIMENTAL GAS INJECTION PROJECT

sures in the latter stage of depletion are little, if any, lower than the original pressure. It is economically feasible to produce the wells at present water-oil ratios in excess of 100 only because of the high operating fluid levels.

Oil production, for the past 15 years, has declined at a fairly constant rate until, at present, most of the wells are producing at oil rates near the minimum possible for profitable operation. An idea of the oil decline rate may be gained from Fig. 6 showing the oil production rate of a number of wells in the area of a current gas injection project obtained from production data prior to the start of gas injection.

The peculiar behavior of several wells in the field suggested the possibility of recovery, by secondary means, of considerable quantities of oil which had been trapped in the reservoir by encroaching water. At intervals during recent years normal, high water-oil ratio wells have been observed to suddenly start producing oil at greatly reduced ratios, sometimes producing several thousand barrels of oil before returning to their normal status. It was visualized, as shown in Fig. 7-a, that sizeable volumes of oil could have been trapped by the encroaching water in irregular upper surfaces of cavernous openings of the limestone. The only means whereby oil so entrapped could be produced is through being forced downward, by some lighter medium such as gas, into the fluid stream moving to the producing wells, as shown in Fig. 7-b. If pressure reduction during past production had been sufficient to cause the liberation of enough solution gas from the reservoir oil to fill these pockets, this oil would have been recovered by natural depletion methods. However, the pressure, as aforesaid, has been maintained by the encroaching water to the extent that it is probable that little, if any, solution gas liberation has occurred in the reservoir. If oil is trapped as visualized, then the only possibility for its recovery would be through the injection of gas to replace the oil.

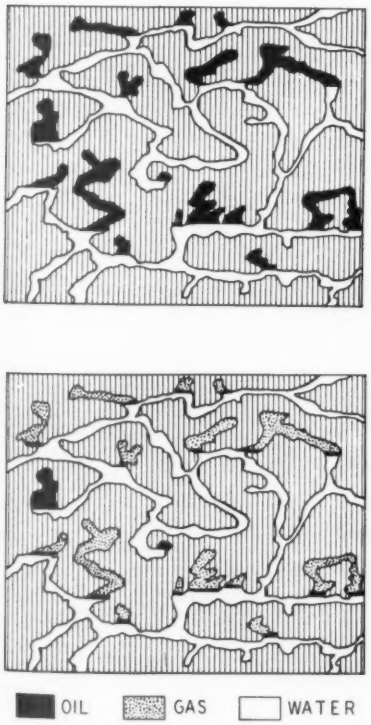

FIG. 7A (TOP) AND 7B (BOTTOM)—RESIDUAL OIL DISTRIBUTION WATER DRIVE CAVERNOUS LIME

In order to test the above discussed possibility, a small scale experimental gas injection project was planned for the field in which gas would be injected by the use of a portable compressor into one well, and the effects on oil production of offset wells observed. The well chosen for injection service was a temporarily abandoned well located centrally in a group of still active producing wells, and about 50 feet below the crest of the structure.

Gas injection was initiated in June, 1946, and has continued to date with operations being somewhat erratic, due to difficulty in maintaining sufficient gas supply, and mechanical trouble with the compressor. The average daily gas injection rate has been somewhat less than 200 Mcf per day. In Fig. 6, it can be observed that the oil production from the wells adjacent to the gas injection well is considerably above the expected decline under primary methods. The increased oil attributable to the injection program, indicated by the shaded area between the expected production curve, is 38,800 barrels. The volume of increased oil was obtained by injection of a total of 135,323 Mcf of gas for an injected gas to increased oil production of 3.49 Mcf per barrel which, of course, is an economically attractive proposition for any reasonable cost of injecting gas.

FIELD "D"

This field is located in Central Kansas and produces from the Viola lime at an average depth of 3,850 feet. The productive area of the field is 520 acres, on which have been drilled 22 producing wells. The producing formation varies from a crystalline lime with cavernous solution porosity to a granular dolomite. Coring of several wells in the field has resulted in very poor recoveries, so it is impossible to establish definitely what fraction of the 40 feet of gross pay interval is porous and permeable. Laboratory analyses of the samples recovered from the cored section indicate an average permeability of less than 10 millidarcys. However, the productivities of the wells are several hundred to several thousand per cent higher than would be predicted from the core data, so it is obvious that communication in the reservoir is through a system of comparatively large secondary channels. From visual observation of drill cuttings and the cores recovered, it is indicated that this system is more probably made up of erosion channels than an extensive fracture system. Further indications of the presence of a system of relatively large interconnected secondary openings is shown by the excellent response to acid treatment.

Wells in the field were completed by setting pipe at the top of the producing zone, drilling in with cable tools, and acidizing with from 1,000 to 3,000 gallons of acid. Increases of productivities after acid treatment varied from a few per cent, on initially very good wells, up to 1,000 per cent of pre-acid productivities on initially small wells. Productivity indices after acid treatment range from 7.0 up to values immeasurably high. On some wells the decrease in the bottom hole pressure from static conditions is too small to be measured at reasonable rates of oil production. Productivities indicated from P.I. data in some cases are in excess of 20,000 barrels of oil per day.

The productive structure is an anticline, with the limits of production being defined on all sides by the water-oil contact. The oil filled closure between the crest of the structure and the original water-oil contact was approximately 70 feet. Despite the fact that most of the wells were completed close to the water-oil contact, little water coning was observed due to the slight pressure draw-down experienced under the limited withdrawal rates. The rise of the water-oil contact has been relatively uniform throughout the field. At present, as indicated by Fig. 8, the average water percentage of the producing wells is about 65 per cent. Properties of the original reservoir oil as shown by several bottom hole sample analyses are as follows:

Saturation Pressure at Reservoir Temperature	1,100 psia
Gas in Solution	350 cu ft/bbl
Relative Volume Compared to Residual Oil	1.214
Viscosity of Bubble Point Oil	1.05 cp
API Gravity of Residual Oil	41°

The original reservoir pressure at a datum of 1,950 subsea was 1,328 psig. During the depletion of the field, it has been possible to obtain excellent bottom hole pressure data since complete pressure build-up occurs in the producing wells within a very short time after they are shut in. Reservoir pressures obtained from quarterly surveys of several key wells distributed throughout the field indicate very slight pressure differences between different parts of the field. Usually the pressure differences between key wells in any survey are in the range of 10 to 30 p.s.i., which is another definite indication of the practically unlimited communication between all parts of the reservoir.

Fig. 8 is a graph of the pertinent production performance data on the field since the time of discovery in 1940. As shown by the figure, a rather sharp pressure decline was experienced in the early depletion of the field. During this period, up to the end of 1943, the field performance data indicated almost complete volumetric control. This was evidenced both by the sharp pressure decline and the start of increase in gas-oil ratios occurring in late 1942 and 1943. However, when the reservoir withdrawal rate was curtailed toward the end of 1943 by reducing the oil production rate from approximately 1,400 barrels to 900 barrels per day, the tendency toward increasing gas-oil ratios was actually reversed and the rate of pressure decline was markedly decreased. At the lower rates of withdrawals experienced during the past 4½ years, the limited water drive has effectively altered the producing characteristics of the reservoir. The sensitivity of the relationship between rate of withdrawals and rate of reservoir pressure decline is shown by Fig. 9, which is a plot of bottom hole pressure and producing rate against cumulative reservoir withdrawals. It can be readily observed from this figure that the sharpest rate of pressure decline experienced during the life of the field was obtained during the period in which the reservoir pressure declined from the original pressure of 1,328 to approximately 1,100 psi. Replacement of reservoir withdrawals during this time was by liquid expansion alone. Below a pressure of 1,100 psi, gas coming out of solution from the reservoir oil supplemented liquid expansion to the extent that, even though withdrawal rates were progressively increasing, the rate of reservoir pressure decline was arrested. It will also be noted from this figure that each time the rate of reservoir withdrawals was changed significantly, a corresponding change in rate of reservoir pressure decline was experienced, with the bottom hole pressure versus withdrawal relationships being practically linear over any period of constant withdrawal rate.

Although it is believed that the nature of the porosity in Field "D" is very similar to that visualized in Field "C", as pictured in Fig. 7, the combined gas expansion and the simultaneous encroachment of water will result in a recovery efficiency higher than is expected in Field "C", due to the fact that released solution gas will be stored in the irregular pockets of the reservoir, and displace the oil therefrom. It is estimated that between 50 and 70 per cent of the original oil in place will be produced under present depletion methods before this field is abandoned, and that the possibilities for future production by secondary recovery methods will be practically nil. As evidenced by gas-oil ratios increasing slightly above solution ratio, the maximum possible quantity of liberated solu-

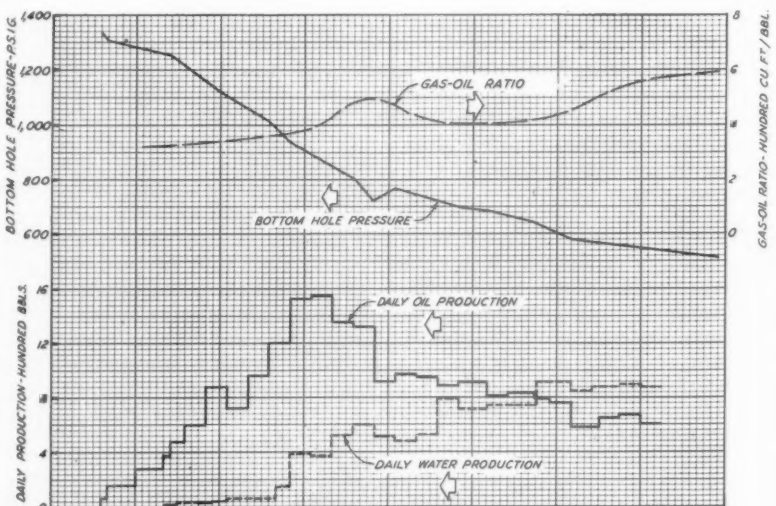

FIG. 8 — FIELD "D" RESERVOIR PERFORMANCE CURVES

tion gas has been stored in the reservoir. Gas-oil ratios have not become excessive, because gas saturation increases and the resulting gas permeability increases have been minimized by practically complete replacement of withdrawn fluids by encroaching water during the past few years. At the same time, pressure maintenance by the encroaching water has minimized losses due to shrinkage of the reservoir oil. This building up of the gas saturation in the reservoir to the maximum possible, without excessive free gas flow at the same time the water was encroaching, has eliminated the possibility of significant volumes of oil being trapped in irregular pockets by the water as shown in Fig. 7-a. In this reservoir, the type of depletion program being undertaken in Field "C" by gas injection has been effectively accomplished by natural means, solely through control of production rates.

Undoubtedly, the depletion program providing the maximum recoverable oil from a reservoir of this type, is fast pressure reduction early in the producing life of the reservoir before significant volumes of water have invaded the fully liquid saturated zones, followed by controlled pressure decline. The first phase of pressure reduction should continue as rapidly as possible to a pressure in the reservoir sufficiently below the bubble point of the oil to cause liberation of enough solution gas to establish the maximum gas saturation that can be maintained without excessive flow of free gas. After this condition has been attained, further pressure reduction should be at low enough rate such that the encroaching water will replace withdrawals to the extent that excessive gas-oil ratios and oil shrinkage will be avoided. If the pressure were allowed to decline rapidly after having reached the above discussed stage of gas saturation, and before encroaching water displaced, to the producing well bores, the oil which had been forced downward from irregular pockets, subsequent encroachment of water could recompress the gas trapped in these pockets and refill them partially with oil. The recovery of this oil then would depend on injecting high pressure gas to again displace this oil downward, and would result in considerably lower efficiency than would be possible under simultaneous pressure reduction and water encroachment. Field "D" probably is one of few fields wherein reservoir conditions are such as to allow this almost perfect control over the natural producing mechanisms.

SUMMARY

There has been proposed, in the literature, a concept of the nature of limestone reservoirs and an interpretation which leads to the conclusion that limestone reservoirs in general are not susceptible to a dispersed type injection program and that such a program cannot materially increase the ultimate recovery of oil. In brief, this concept proposes that limestone reservoir rocks are made up of two types of porosity, intermediate and intergranular. It has been visualized that the intergranular rock, constituting a large portion of the reservoir void space, and having low permeability, is interconnected by fissures or by continuous, relatively thin zones of intermediate porosity having considerable greater permeability. It is then reasoned that this system of continuous highly permeable intermediate porosity acts as a system of short circuiting conduits which enable the production of oil from portions of low permeability rock, remote from the well bore, that otherwise would produce into the wells at impractical rates.

Furthermore, this theory concludes that the presence of such interconnected passages may nullify the benefits of gas injection by unduly concentrating the flow of the injected gas; resulting in a program whereby the injected gas is cycled through a small portion of the reservoir, represented by the interconnected intermediate type porosity, without appreciably increasing the ultimate recovery of oil. It is quite possible that these conditions do exist in some limestone fields, and may be critical in determining the success of either a gas injection or water flood program; however, performance of many limestone fields indicate that the above proposition is possibly the exception rather than the rule for limestone reservoirs.

It must be recognized that the term "limestone reservoirs" denotes a class of reservoirs in which there are many different types having a wide range of characteristics. The four example fields discussed in this paper represent a few limestone reservoirs where an interpretation of performance definitely indicates that the concept stated above and its implications, in regard to the susceptibility of such reservoirs to secondary recovery efforts, does not apply.

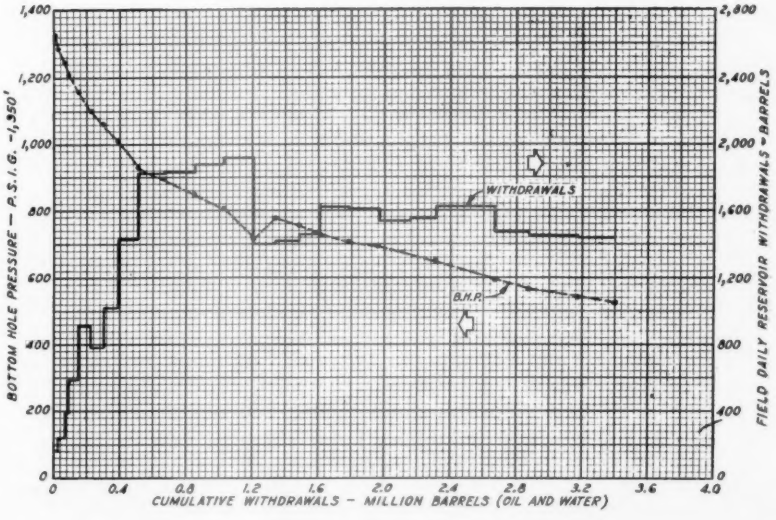

FIG. 9 — FIELD "D", RESERVOIR PERFORMANCE CURVES

Prospective secondary recovery programs in limestone fields in general should not be condemned on the basis of tentative conclusions as to the nature of limestone reservoir rocks, and an interpretation of these characteristics which leads to the conclusion that it is impossible to displace oil by means of an extraneous displacing medium except in a very small portion of the reservoir, represented by the intermediate type porosity.

It appears impossible to adequately evaluate the properties of the various type of porous media found in limestone reservoirs and their inter-relation from presently developed core data and geological information. The problem of predicting, in advance, the susceptibility of a limestone reservoir to secondary recovery methods can only be solved, at present, by a comprehensive analysis of the performance history of that field. This must necessarily remain the case until more adequate methods are evolved to account for the effects upon performance of the many, now immeasurable, variations of limestone reservoir properties.

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